S
338.26
M26bpR
1987

HRI
Headwaters Research Institute, Ltd.

Expanded Steering Committee Meeting

January, 1987

BERKELEY PIT
RE-INDUSTRIALIZATION AND MINERAL RECOVERY PROJECT

NOV 1 2 1991

MONTANA STATE LIBRARY
S 338.26 M26bpr 1987 c.1
Berkeley Pit re-industrialization and mi
3 0864 00062502 3

HEADWATERS RESEARCH INSTITUTE, LTD.

BERKELEY PIT RE-INDUSTRIALIZATION AND MINERAL RECOVERY PROJECT

EXPANDED STEERING COMMITTEE MEETING

January 20 - January 23, 1987

Copper King Inn

Butte, Montana

This material is the result of tax-supported research and as such is not copyrightable.

This publication was prepared by:

Headwaters Research Institute
44 West Sixth
Helena, Montana 59601

Organizations that have assisted Headwaters Research Institute in funding the publication of this book are:

Montana Department of Commerce
Helena, Montana

Montana College of Mineral Science and Technology
Butte, Montana

Montana State University
Bozeman, Montana

TABLE OF CONTENTS

VISION

Multiobjective Technology
Dedication
Feasibility
List of Participants
Workplan

BACKGROUND PAPERS

Butte Mineflooding and the Berkeley Pit 1
by John Sonderegger
Treatment of Berkeley Pit Water 5
by Howard S. Peavy
The Mineralogy of the Ores of the Butte Mining District . . 16
by Lester G. Zeihen
A Review of Butte Metallurgy. 23
by William R. Stern
Economics of Metals Potentially Recoverable From the Berkeley Pit 41
by John C. Brower

CONCEPT PAPERS

Superfund Amendments of 1986: A Vision for Montana's Economic Future 53
by Steve Browning
Organizational Concept: Headwaters Research Institute . . . 58
by John Driscoll
Outline of a Concept for Water Reclamation/Mineral Recovery from the Berkeley Pit in Butte 68
by Walter Juda
Proposed Water Cleanup of the Berkeley Pit. 71
by Roberta Beery, Terry Davis, and Teri Henderson
Reverse Osmosis: Berkeley Pit Project 79
by Tom Flower, Joel Maroney, Scott Romine and Glenn Stroud
Tentative Reclamation Costs for Berkeley Pit Water 87
by Paul L. Wichlacz
Questions Posed by the Expanded Steering Committee 90

APPENDIX

Butte Water Company background material
Water for Thirsty Cities
by George A. Whetstone

Digitized by the Internet Archive
in 2013

http://archive.org/details/berkeleypitreind13expa

MULTIOBJECTIVE TECHNOLOGY

"The point was not missed that the greenhouse effect (for example), like many other modern problems, is a technical problem looking for a technical fix. Building a system for one purpose and then rebuilding it for another purpose has a certain inelegant, patchwork quality about it. Haefele seems to point to the twenty-first century when he says, 'Technology should no longer remain tied to a single-objective solution. We're paying too high a price for it. It should become multiobjective in nature and development. It should become coherent, synthetic. This would automatically take care of the imbedding of technology in the environment and the bigger question of the interface between technology and society. The dichotomy would disappear.'"*

---

* Lecture by Dr. Robert White, President of the (U.S.) National Academy of Engineering, to the Electric Power Research Institute Seminar: "What Will Life Be Like in the Year 2006?" Reference is to insights by Wolf Haefele, Chairman of the Board, Kernforschungsanlage Julich GmbH, Federal Republic of Germany (also attending).

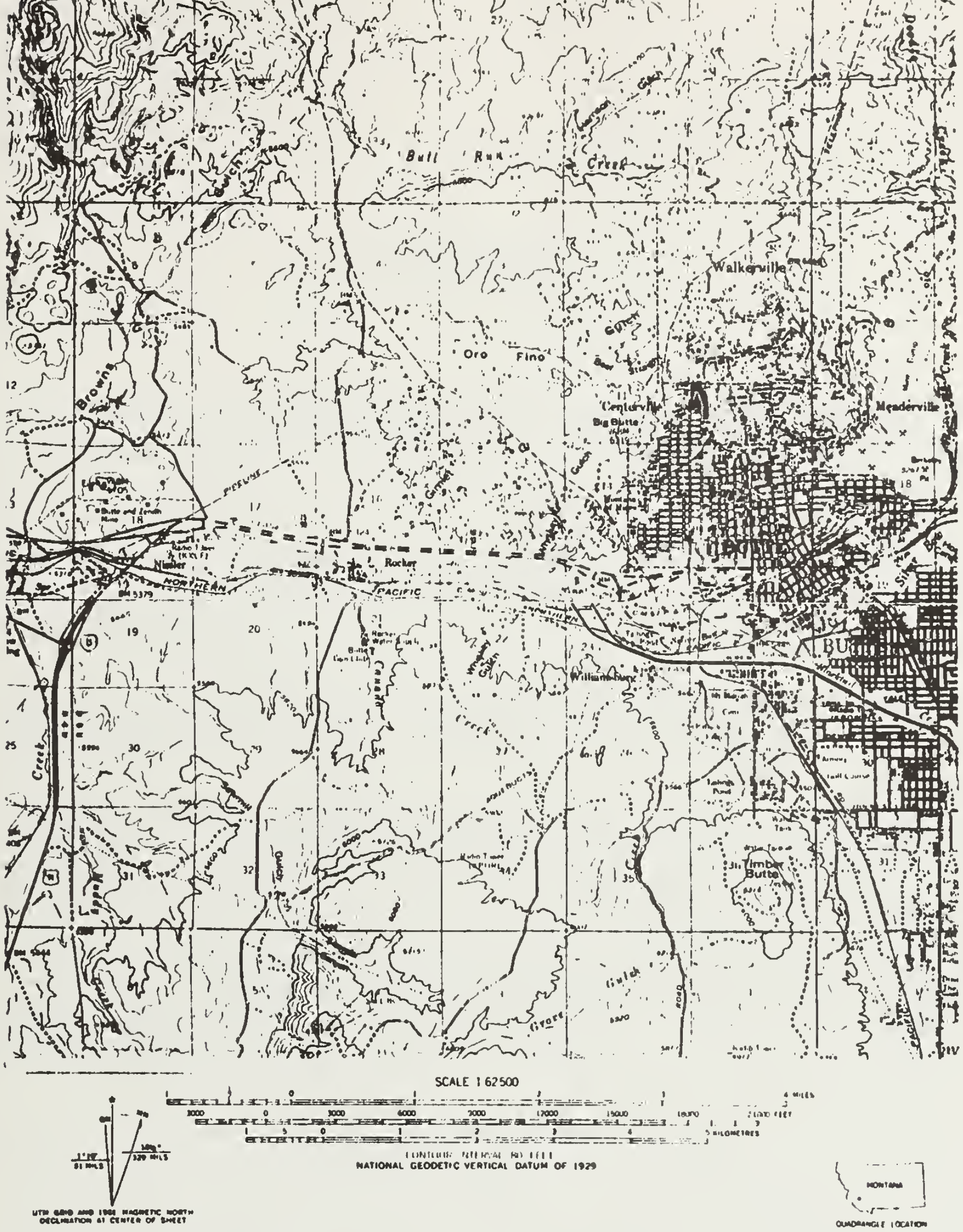
DEDICATION

This effort is for the people who live in the headwaters of the Columbia River, particularly in the region around "The Richest Hill on Earth," Butte, Montana.

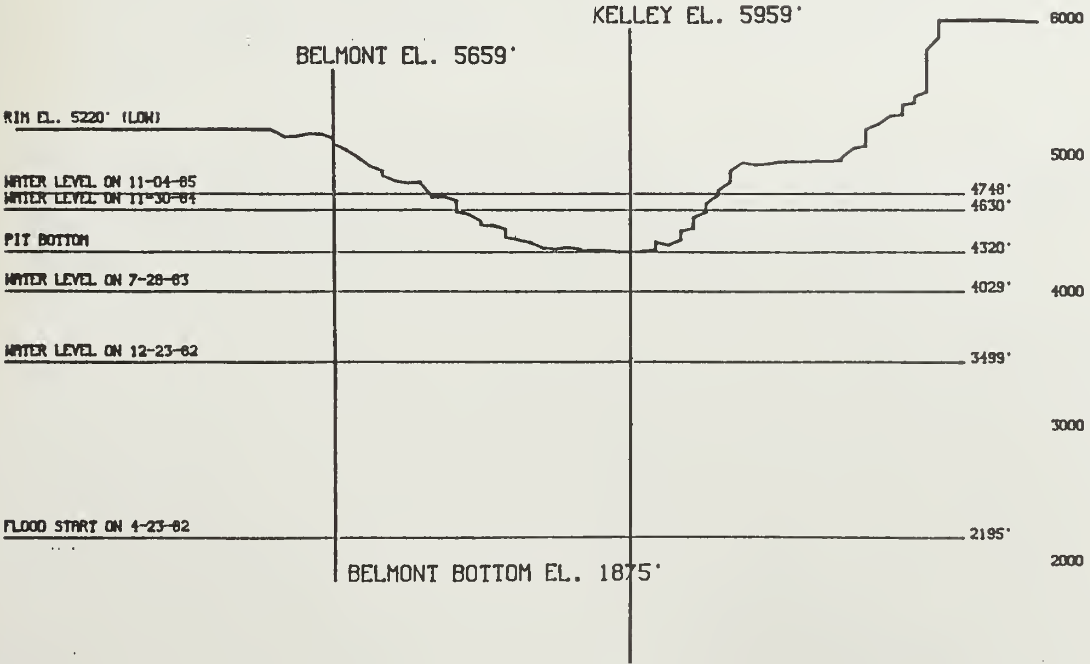
The area, a major Superfund Enforcement Site, centers around a city atop 41 miles of vertical shafts and 2,400 miles of horizontal tunnels. Connected to the underground workings, at the east edge of the Butte Hill, is an enormous abandoned open pit mine. Both the pit and the underground network are filling with water at the rate of about eight feet each month; the deepest shafts now have over 2,650 feet of water and the pit has over 550 feet. The rock, now perforated from previous mining technologies, contains major deposits of a wide variety of minerals; the types are reflected in the content of the water now flooding the mines.

On the surface, the people are currently more concerned with the sad state of their community water system, which is in certain need of major costly remedy to its source, transmission, filtration, and distribution subsystems.

The material gathered here is to help the people of Butte unleash their greatest resource: creativity. Perhaps from this food for thought can come a coherent, synthetic, and efficient water and wealth-creating system, suitable to the people of Butte in the twenty-first century.



CROSS SECTION LOOKING WEST



FEASIBILITY

In January 1987, forty individuals with competent professional, technical, or scientific backgrounds met as an "expanded steering committee" to discuss the question:

> "What has to be overcome to develop a process that will both clean the water in the Berkeley Pit and process the minerals in the Butte Hill?"

In a highly structured two-day series of discussions, the group first discovered that the three most important areas of concern were:

1. organizing such an effort;
2. assessing the range of technologies that might accomplish the effort; and
3. characterizing the site, whether it be a resource or a problem.

Next, the group sought to find if there are any reasons whatsoever that would make such an effort non-feasible. There were none. The project is feasible.

The greatest threats to feasibility are thought to be:

1. local belief that there is no problem (or opportunity);
2. lack of cooperation between the "large stake holders"; i.e. the potential responsible party under Superfund (ARCO), the current property owner (Montana Resources, Inc.), the main enforcement agency (U.S. EPA), and key enforcement agencies in Montana state government (Health, Natural Resources, and Lands); and
3. no funding, particularly in the early stages of project development.

The general feeling was that the threat of cleanup enforcement authority by EPA is essential to the success of this project, but that actual direct exercise of that enforcement power is a "default option" that should be pursued if this more "positive effort" fails.

LIST OF PARTICIPANTS

J.N. Hartley
Manager, NWHWC
Battelle N.W.
Richland, Washington

D.W. Kneebone
President/General Mgr.
Occu Safe
Butte, Montana

L.G. Zeihen
Adjunct Curator
MT Tech Mining Museum
Butte, Montana

Dan Powers
Sanitarian
Butte Health Dept.
Butte, Montana

P.C. Walkup
Manager, Chem. Proc. Dev.
Battelle N.W.
Richland, Washington

R.C. Bishop
Architect, Val-Desta MT
Mining Mfg. & Minerals
Butte, Montana

Howard Peavy
Director,
Water Research Center
Bozeman, Montana

Bob Hunter
Teaching Assistant
MSU Civil & Ag Eng. Dept.
Bozeman, Montana

Kathy Hadley
Vice-President
NCAT
Butte, Montana

Peter N. Jones
President
MSI Detoxification, Inc.
Bozeman, Montana

Neal Egan
Technical Assistant
MSE, Inc.
Butte, Montana

John Sonderegger
Professor, MBMG
Montana Tech
Butte, Montana

Kevin Harvey
Scientist
MSI Detoxification, Inc.
Bozeman, Montana

Allen Bjergo
Extension Service
Montana State University
Bozeman, Montana

Arnold Silverman
Professor of Geology
University of Montana
Missoula, Montana

Orin Zimmerman
Technical Director
EPRI
Palo Alto, California

LIST OF PARTICIPANTS
(continued)

Bill Stern
Consultant
Prototech, Inc.
Tucson, Arizona

Walter Juda
President
Prototech, Inc.
Tucson, Arizona

Allan Zunkel
President
Jen H. Reimers USA
Houston, Texas

Koehler Stout
Mining Consultant
1327 Granite
Butte, Montana

Paul Wichlacz
Scientist
INEL
Idaho Falls, Idaho

John Brower
Professor of Mineral Economics
Montana Tech
Butte, Montana

Henry McClernan
Dean of Research
Montana Tech
Butte, Montana

George Hatch
ARCO
Route 2, Box 2080
Whitehall, Montana

Pete Pryfogle
INEL
Idaho Falls, Idaho

Mike Rubich
Superfund Coordinator
MT Dept. of Health
Helena, Montana

Charles Palagi
MRI
600 Shields
Butte, Montana

Ted Dodge
Coordinator, HRI
400 North Main
Butte, Montana

Rich Griffith
Reclamation Coordinator
Butte - Silver Bow
Butte, Montana

John Driscoll
MT Public Service Commission
270 Prospect Avenue
Helena, Montana

John O'Donnell
Director, Energy Utility
Montana Power Company
Butte, Montana

Howard Johnson
Coordinator, Clark Fork Project
Governor's Office
Helena, Montana

David Sharpe
Extension Service
Montana State University
Bozeman, Montana

WORKPLAN

Several important tasks need to be accomplished in the early stages of this project:

1. The decision-making organization, if devised like the one for HRI, would have to allow operational advice from the "major stake holders" (ARCO, EPA, MRI, and state agencies) and technical advice from individuals and organizations such as those gathered for the Expanded Steering Committee.
2. The project should be managed through a Project Team, which would guide at least two subproject teams (Assessment and Characterization), commission a legal white paper on liability, and develop a long-term project strategy for consideration by the Board.
3. The Assessment Team would review a wide range of technological combinations to determine the most suitable, and the likely relationships of cost to revenues.
4. The Characterization Team would review available information on the water and mineral resources, devise a sampling plan, develop a memorandum of understanding with MRI for access to the water, and provide information according to the needs of the Assessment Team.

This first stage would take about 18 months. At the joint level the cost would be about $50,000; each subproject effort is likely to cost $100,000. Some support might be expected from interested private and public research entities.

BACKGROUND PAPER

BUTTE MINEFLOODING AND THE BERKELEY PIT

By

John Sonderegger

Montana Bureau of Mines and Geology

Dr. John Sonderegger, a member of the faculty at the Montana College of Mineral Science and Technology, is a hydrogeologist with the Montana Bureau of Mines.

Water quality samples from the pit were collected on November 21, 1984 and June 18, 1985 when the Department of State Lands had a helicopter fly into the Berkeley Pit and drop a bailer into the water to collect samples. On October 17, 1986, the Headwaters Research Institute had a helicopter land a boat and crew in the pit to collect samples at various depths using a peristaltic pump. The analytical results for these samples are presented in Table 1.

A planning error reduced the value of the 1986 sampling. It was expected that the crew would backpack the sampling equipment and samples out of the pit. To minimize the weight, conductivity and pH/redox meters were not taken into the pit. However, with the roughly 100 pounds of sampling and safety equipment, it was not feasible to safely climb out of the pit. Future sampling trips should plan on helicopter assistance in and out of the pit, and carry additional sampling equipment plus a sonar unit to permit positioning of the boat with respect to the pit's bathymetry.

Previous sampling results using the helicopter and bailer are presented in Table 2 for comparison. From these data it appears reasonable to expect the pit water pH to be between 2.5 and 3.0. The higher value is more probable now that the coarse concentrator discharge stream has been directed into the pit. Utilizing the ratio of arsenic (III) to arsenic (V), it is possible to calculate the oxidation-reduction potential of the water using the following equation

$$pe = 11 - 3/2 \text{ pH} - 1/2 \log \left\{ AH_3ASO_3^{\circ} / AH_2ASO_4^{-} \right\}$$

from Cherry, and others (1979). If we assume a pH of 3.0, the calculated pE values range from 6.9 to 7.2, with the lowest values occurring at depths of 220 and 330 feet. These values show that the water in the pit is fairly oxidized and that the metals values in the water will be limited mainly by the pH of the pit water. Consequently, continued discharge of the high pH, coarse concentrator waste stream into the pit may lead to reduced metal concentrations as can be seen from the attached figure. The figure was constructed for a dissolved iron concentration of 1,000 milligrams per liter (mg/L) which is appropriate for the deeper samples collected in 1986; the species and phase boundaries were calculated using equations from Stumm and Morgan (1981, p. 447).

Results from sampling the Kelley Shaft at the end of October, 1986, are only partially available (Table 3). However, the 1985 sample information is presented in Table 4 for comparison purposes. The major economic differences are the higher copper and lower zinc concentrations in the pit water samples are compared to the shaft samples. The deeper shaft samples contain greater concentrations of magnesium, potassium, iron, manganese, and aluminum, suggesting a more intensive leaching of ore and host rock, despite the probably higher pH values.

The computer program WATEQF (Plummer and others, 1976) was used to test the conclusion that the pit waters were nearly saturated with respect to amorphous ferric hydroxide [$Fe(OH)_3$] by using the calculated values from the arsenic redox couple and the estimated pH of 3.0. Anion concentrations, necessary to run the program, were estimated at 17.7, 2620, and 5 mg/L for Cl, SO_4, and F, respectively, for the 0.5-foot sample. For the 390-foot sample, the estimated Cl, SO_4, and F values were 17.7, 5610 and 10 mg/L, respectively. The calculations showed the surface and deep samples to be undersaturated with respect to $Fe(OH)_3$ by about 1 pH unit, which supports the conclusion drawn from the attached figure. Also of interest is the fact that both samples are calculated to be slightly supersaturated with respect to gypsum.

The major drawbacks to the data presented are:

1. The redox state for arsenic species may not represent the effective redox state of iron species (Lindberg and Runnels, 1984; Freeze and Cherry, 1979, p. 120; Stumm and Morgan, 1981, p. 462). While filtering the surface sample, we noted some reddish material collecting on the filter; presumably, this was $Fe(OH)_3$. The lower metals concentrations in the surface and 110-foot samples suggest that ferric hydroxide is forming and that copper and zinc are coprecipitating with the iron hydroxide.

2. Field measurements of pH, temperature, and Fe(II) - Fe(III) were not obtained.

The presence of the reddish precipitate suggests that the lower metals values are not solely the result of inflowing surface water with lower metals concentrations, but also that these lower values result in part from loss by precipitation. Thus the economic viability of water cleaning processes will, in part, be dependent upon whether or not the pit continues to be used as a receptacle for high pH wastes from the concentrator.

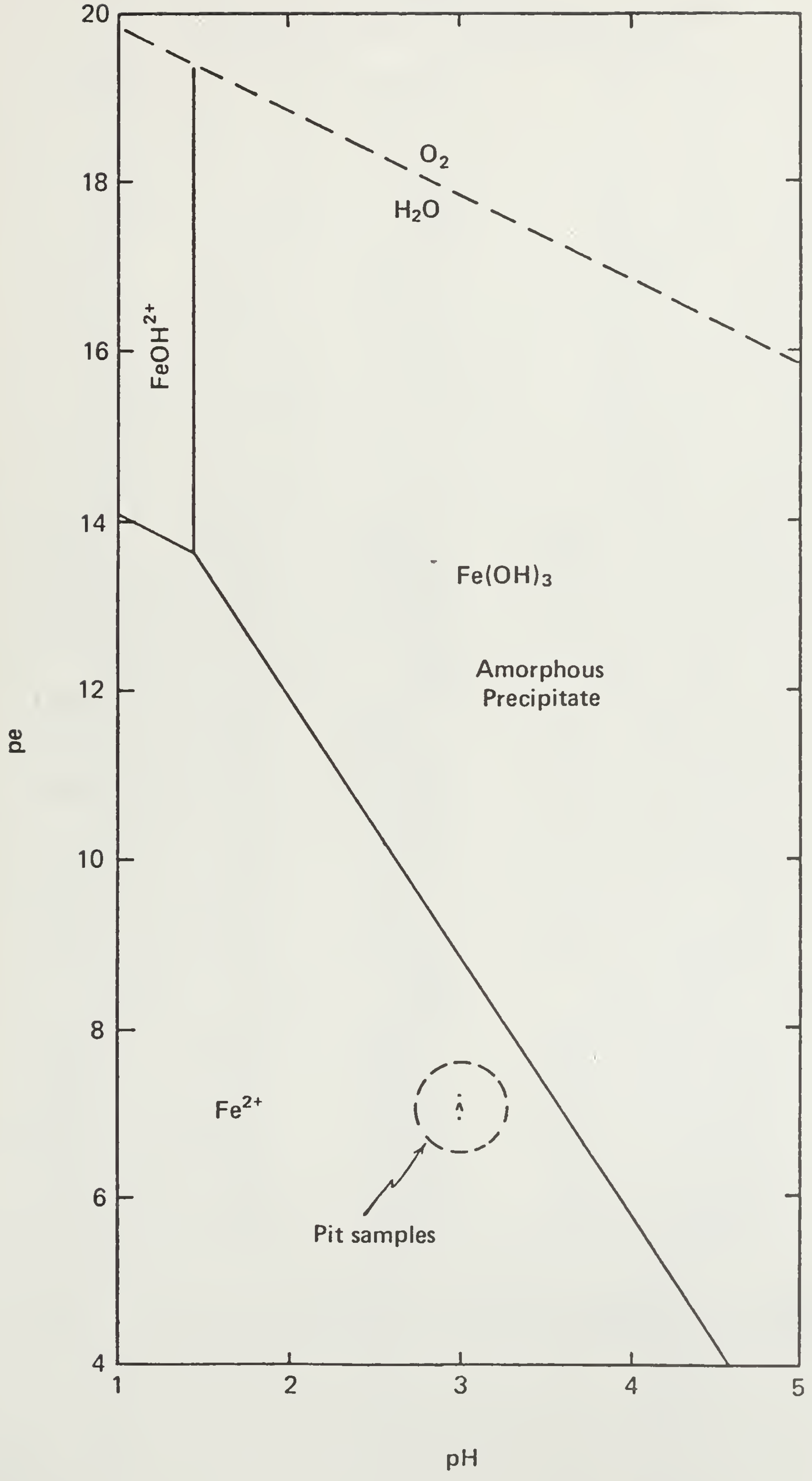

20
18
16
14
12
10
8
6
4
pe
1
2
3
4
5
pH
O_2
H_2O
$FeOH^{2+}$
$Fe(OH)_3$
Amorphous Precipitate
Fe^{2+}
Pit samples

Table 1
Berkeley Pit Samples, October 17, 1986 (mg/L)

Depth (ft.)	0.5	110	220	330	390	390*
Temp (°C)	---	---	---	---	---	---
pH	---	---	---	---	---	---
Ca	425	457	450	457	456	455
Mg	149	250	291	310	310	313
Na	59.3	64.7	65.8	66.5	65.4	65.8
K	12.9	19.5	24.3	26.2	26.2	27.8
SiO_2	78.9	104	108	109	111	110
Fe	177	685	918	1,010	1,020	1,060
Mn	64	122	144	154	156	160
Al	91.6	171	192	201	203	209
Ag	0.019	0.032	0.037	0.043	0.043	0.043
B	0.15	0.25	0.33	0.39	0.40	0.28
Cd	1.0	1.62	1.74	1.80	1.69	1.70
Cu	114	196	204	214	213	209
Li	0.16	0.23	0.25	0.27	0.26	0.26
Mo	0.14	0.21	0.23	0.28	0.25	0.26
Ni	0.46	0.79	0.91	0.97	0.95	0.99
PO_4 as P	<.1	0.5	0.5	0.5	1.1	1.4
Sr	0.86	1.03	1.02	1.02	1.00	0.99
Ti	0.01	0.015	0.022	0.014	0.027	0.062
V	0.029	0.22	0.27	0.31	0.31	0.31
Zn	178	375	460	472	477	492
Zr	<.004	0.023	0.049	0.062	0.062	0.065
As	0.016	0.033	0.041	0.050	0.123	0.188
As (III)	<.001	0.0023	0.005	0.0053	0.0043	0.0047
Co	0.57	0.94	1.05	1.06	1.07	1.07
Cr	0.004	0.042	0.050	0.055	0.047	0.048

*unfiltered sample; all samples acidified with 1/2% nitric acid

Table 2
Earlier Berkeley Pit Samples (mg/L)

Date	6/18/85	6/18/85	11/21/84	11/21/84
Depth (ft.)	1.0	100	1.0	62
Temp (^{o}C)	10.2	10.4	5.6	6.5
pH	2.26	2.48	2.64	2.78
Ca	412	435	455	447
Mg	148	261	204	236
Na	64.8	60.3	63.2	61.7
K	7.9	8.8	4.9	4.4
SiO_2	85.6	100	83.6	87.6
Fe	114	451	214	256
Mn	68.1	116	87.5	106
Al	86	172	120	142
Ag	0.033	0.043	0.017	0.030
B	0.10	0.15	0.11	0.20
Cd	1.00	1.62	1.23	1.54
Cu	63	229	89.6	164
Li	0.11	0.15	0.10	0.12
Mo	0.07	0.20	0.17	0.31
Ni	0.47	0.83	0.63	0.85
PO_4 as P	<.1	<.1	0.1	<.1
Sr	0.97	0.90	0.86	0.88
Ti	0.076	0.082	0.079	0.094
V	0.031	0.168	0.028	0.066
Zn	134	329	196	255
Zr	0.031	0.047	0.019	0.035
As	0.021	0.426	0.054	0.197
Co	0.064	1.17	0.085	0.98
Cr	0.048	0.092	0.061	0.097
Cl	12.3	8.3	12	12.3
SO_4	3,200	5,550	3,707	4,410
NO_3 as N	0.16	0.23	0.20	0.12
F	3.7	13.6	4.2	5.8
Br	<.1	<.1	<.1	<.1
Pb	---	---	0.17	0.16

Table 3

Kelley Shaft Samples, October 30, 1986* (mg/L)

Depth (ft.) below S.W.L.	2.0	312	1,112
Temp (°C)	21.6	19.8	20.6
pH	4.9	4.94	4.05
Ca	459	460	459
Mg	264	264	418
Na	53.3	51.5	59.5
K	34.2	33.1	63.2
SiO_2	30.4	29.8	53.6
Fe	430	726	1,950
Mn	96.7	95.9	169
Al	11.5	10.3	164
Ag	0.008	0.015	0.037
B	0.26	0.27	0.38
Cd	<.002	<.002	0.012
Cu	0.70	0.54	1.67
Li	0.064	0.067	0.18
Mo	0.090	0.29	0.50
Ni	0.30	0.28	0.74
PO_4 as P	1.0	1.0	6.8
Sr	2.57	2.46	2.00
Ti	0.018	0.030	0.048
V	0.002	0.010	0.088
Zn	232.	234.	510.
Zr	0.053	0.053	0.053
As			
Cr	<.002	<.002	<.002
Cl			
SO_4			
NO_3 as N			
F			
Br			

* Preliminary results

Table 4
Kelley Shaft Samples, May 30, 1985 (mg/L)

Depth (ft.) below S.W.L.	2.0	242	555	967
Temp (°C)	17	18.4	30.2	29.2
pH	4.3	4.8	3.5	3.5
Ca	494	489	520	517
Mg	301	370	1,012	978
Na	131	86.4	102	97.2
K	134	85.8	184	186
SiO_2	41.7	43.6	131	128
Fe	871	1,240	6,200	6,030
Mn	87.2	112	456	439
Al	53.9	63.9	841	799
Ag	0.013	0.021	0.12	0.12
B	0.27	0.39	0.33	0.60
Cd	0.49	0.83	1.28	1.17
Cu	10.6	10.9	6.20	6.48
Li	0.10	0.11	0.55	0.53
Mo	0.26	0.33	0.77	0.75
Ni	0.43	0.53	2.20	2.13
PO_4 as P	0.1	0.1	0.5	0.1
Sr	2.12	2.23	1.56	1.60
Ti	0.065	0.079	0.16	0.15
V	0.093	0.13	1.63	1.60
Zn	457	596	1,590	1,550
Zr	0.053	0.073	<.004	0.49
As	1.21	1.87	16.58	16.13
Cr	0.051	0.066	0.33	0.32
Cl	29	30.5	16.6	17.5
SO_4	5,410	6,440	24,300	23,500
NO_3 as N	2.3	0.12	4.07	0.68
F	13.1	16.	94.	88
Br	0.1	<.1	<.1	<.1

REFERENCES CITED

Cherry, J.A., A.U. Shaikh, D.E. Tallman, and R.V. Nicholson, 1979, "Arsenic species as an indicator of redox conditions in groundwater," Journal of Hydrology, v. 43, pp. 373-392.

Freeze, R.A. and J.A. Cherry, 1979, Groundwater, Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Lindberg, R.D. and D.D. Runnels, 1984, "Ground Water Redox Reactions: An Analysis of Equilibrium State Applied to Eh Measurements and Geochemical Modeling," Science, v. 225, no. 4665, pp. 925-927.

Plummer, L.N., B.F. Jones, and A.H. Truesdel, 1976, WATEQF - A FORTRAN IV version of WATEQ, a computer program for calculating chemical equilibrium of natural waters: U.S. GEological Survey Water Resources Investigation 76-13, 61 p.

Stumm, Werner and J.J. Morgan, 1981, Aquatic Chemistry (2nd ed.): New York, John Wiley and Sons, 780 p.

TREATMENT OF BERKELEY PIT WATER

By

Howard S. Peavy
Water Resources Center,
and
Robert M. Hunter
Department of Civil and Agricultural Engineering,

Montana State University

Dr. Howard Peavy, a member of the faculty at Montana State University, is the Director of the Montana University System Water Resources Center, an inter-university research organization chartered by the Montana Board of Regents.

Dr. Robert Hunter is a member of the faculty at Montana State University in the Department of Civil and Agricultural Engineering.

As stated in other papers prepared for the symposium, the water level in the Berkeley Pit is rising at a rate that exceeds the original estimate. At some point, this water will reach an elevation sufficient to cause interaction with local groundwater and, subsequently, surface water. The length of time required to reach this level cannot be predicted exactly but may be as little as four years. Because the quality of water in the pit is not compatible with that of local surface and groundwater, ultimate removal and disposal or reuse in an environmentally sound fashion will be required. This will undoubtedly require some kind of treatment.

The purpose of this paper is to identify processes that are capable of treating Berkeley Pit water to a pre-selected level of quality. In this paper, the pre-selected level of quality will be that required by the Environmental Protection Agency (EPA) for wastewaters discharged from copper mines to surface waters. These standards, known as Best Practical Technology Currently Available (BPTCA) are as follows:

Table 1
BPTCA Standards for Copper Mine Discharges
(EPA 1978)

Parameter	Units	30-day Average	24-hour Max.
pH	pH Units	6 - 9	6 - 9
Total Suspended Solids	mg/l	20	30
Copper	mg/l	0.15	0.30
Lead	mg/l	0.3	0.6
Mercury	mg/l	0.001	0.002
Zinc	mg/l	0.75	1.5

The present quality of water in the pit was described by John Sonderegger and includes many substances not covered by the EPA standards for copper mine effluent. These include additional metals and several species of minerals. The treatment schemes proposed in this paper further assume that the concentrations of these materials will be reduced to the point where they will be compatible with local ground and surface waters. This level of quality may exceed that required for some practical uses of the reclaimed water but may not be sufficient for others.

For instance, the concentrator at the existing operations near the Pit might well be able to use water of significantly lower quality than that represented in Table 1. On the other hand, water used for other nonpotable purposes such as irrigation, stream flow augmentation, etc. might require a much higher quality. Because future use of the water is not currently known, the above quality standard appears to be a reasonable objective.

Because matter can neither be created nor destroyed, the contaminants in water cannot be eliminated. Treatment processes are therefore designed to separate contaminants from the water, producing a higher quality water and a concentrated contaminant stream. Chemical conditioning and/or changes in phase of the contaminants are often necessary to accomplish this. The resulting concentrated waste stream must then be dealt with in an environmentally safe manner.

The goals of the overall project under consideration here include recovery of the metals and, possibly, minerals from the water. The concentration of these materials in the waste stream may aid in the recovery in some instances. In other instances, change in composition of the material necessary to accomplish removal may make recovery more difficult. This subject is beyond the scope of this paper and must be addressed in the broader context of an interdisciplinary group. Therefore, this paper will concentrate on processes designed to produce a product water stream of acceptable quality. The nature and composition of waste streams will be identified for consideration in future discussions.

WASTEWATER TREATMENT ALTERNATIVES

A wide variety of treatment processes are capable of reducing acidity, suspended solids and the dissolved metal and mineral content of water. Some processes have been used for decades; others have been more recently applied to this problem. The more promising alternatives are discussed in this section. Those alternatives are lime precipitation, sulfide precipitation, ion exchange, and reverse osmosis. Turbidity removal may be accomplished concurrently with some of the alternatives, but may be required as a separate operation. Each alternative is briefly described in terms of the process, product stream, sludges and sidestreams, and its advantages and disadvantages.

Lime Precipitation

Lime precipitation has gained widespread use in the copper mining and processing industries as an economical and effective wastewater treatment process. The U.S. Environmental Protection Agency (EPA) has

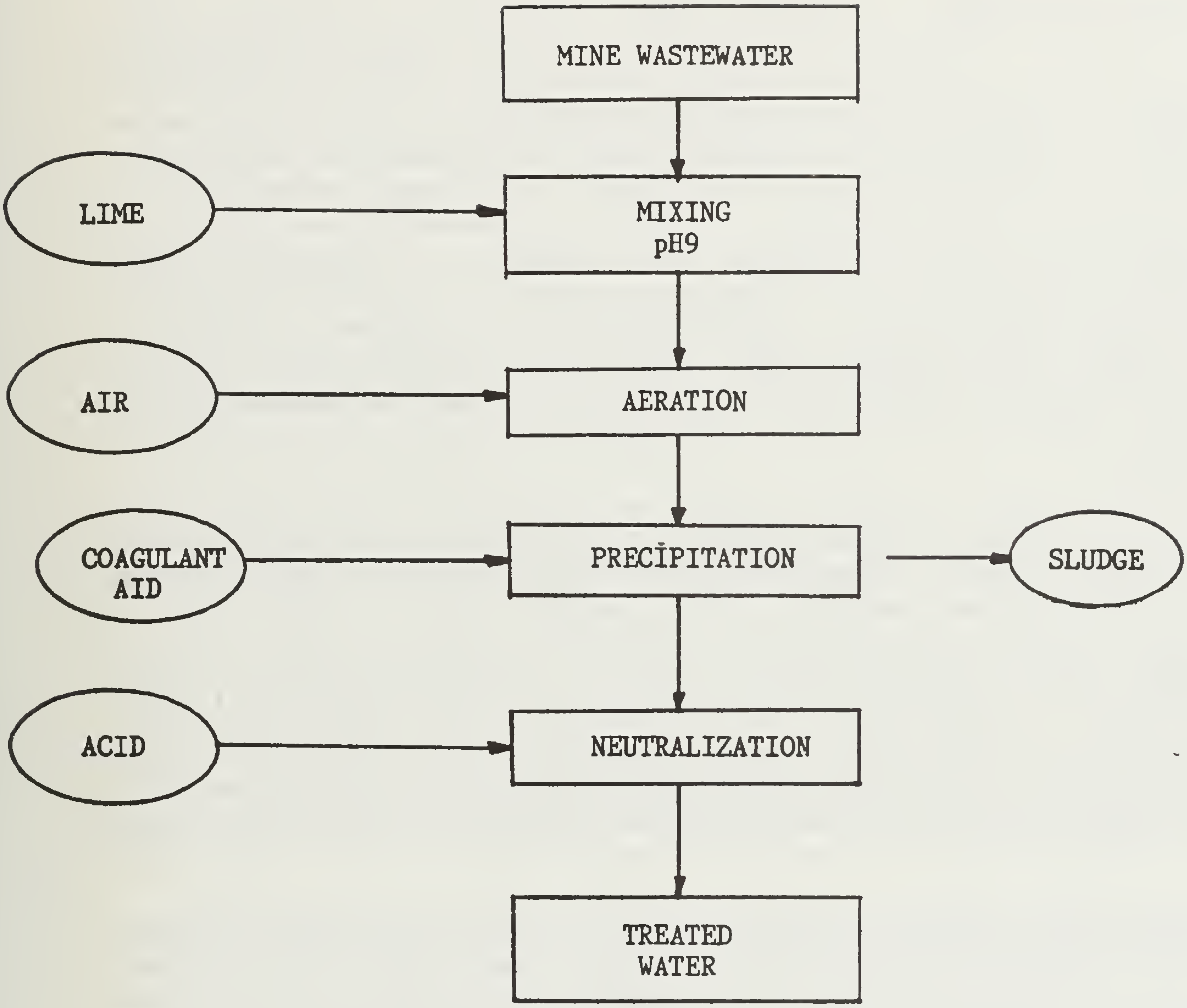


FIGURE 1.
LIME PRECIPITATION

based its proposed discharge requirements (effluent limitation guidelines) on the use of this technology. (EPA, 1978)

Process Description. A schematic flow diagram for a treatment system incorporating lime precipitation is presented in Figure 1. Generally, a lime slurry is mixed with incoming wastewater. Often the mixture is aerated to convert dissolved iron to a form that is more readily precipitated. In general, sufficient lime (or other base) must be added to attain a pH of about 9 to ensure effective heavy metal removal by precipitation as metal hydroxides. With proper operation, very high metal removal rates (over 95 percent) can be achieved. Sometimes the addition of a settling aid such as alum or polymer is required to aid in removal of precipitates. This will probably not be necessary, because the pit water contains several metal species that form hydroxide flocs and would serve as settling aids. The process can be accomplished in earthen basins, conventional sedimentation tanks, or in solids contact reactors.

It is also often necessary to neutralize lime treatment effluents prior to discharge. This is accomplished by adding an acid, usually sulfuric acid, to the treated water.

Product Water Characteristics. Because Berkeley Pit water contains large sulfate concentrations, lime precipitation would result in high concentrations of dissolved calcium and sulfate. In effect, these salts would replace the metals removed during treatment. These materials, along with sodium and associated anions, result in a water with excessive dissolved solids that could have limited use.

Sludges and Sidestream Characteristics. Lime precipitation produces large volumes of metal hydroxide sludges. The sludges contain essentially all of the dissolved metals originally in the water plus those introduced during treatment. Because different metals precipitate most effectively at different pH values, it is theoretically possible to segregate iron precipitates from more valuable precipitates. Sludges can be dredged from settling ponds or pumped from settling tanks and acid leached for recovery of metal values. The common processes of cementation or electrowinning can be used to recover metals from these solutions. Freezing has been shown to be an effective means of concentrating lime precipitation sludges to assist in metals recovery.

Advantages and Disadvantages. Lime precipitation is a proven and relatively economical process. A variety of bases, including limestone (which is available in Montana), can be used in the process. The disadvantages of the process include production of large volumes of often dilute sludges that contain sufficient concentrations of metals to be toxic, but often insufficient concentrations to be economically recoverable. The turbidity-causing suspended solids in the Berkeley Pit would precipitate along with the metallic hydroxides, causing additional difficulties with metals recovery.

Sulfide Precipitation

Sulfide precipitation can be used to accomplish higher degrees of metal removal than are possible with lime (hydroxide) precipitation. However, sludge disposal constraints often limit the use of this technology.

Process Description. A schematic flow diagram for sulfide precipitation is presented in Figure 2. Mine wastewater is first neutralized to ensure that the sulfide will remain in solution. At acid pH values, the chemical can be released from solution as the poisonous gas hydrogen sulfide. Care must also be taken to ensure that excess sulfide is oxidized prior to discharge, as this ion is also toxic.

Sulfide ions can be obtained from barium sulfide or sodium sulfide. Barium sulfide has the advantage of not persisting in treated water as barium is completely precipitated as barium sulfate. Sodium sulfide, on the other hand, is often available as a byproduct of industrial operations. It can also be made by reduction of sodium sulfate, a waste product of acid leaching.

Highly effective removals of copper, iron, mercury, nickel, lead, zinc, and other heavy metals can be achieved by sulfide precipitation. Removal of 99 percent and above are commonly reported. (Robinson and Sum, 1980)

The sulfide precipitation process has been used as the second stage in a process train that includes pretreatment by lime precipitation at a lower pH. Pretreatment by lime to a pH of about 5 can be used to remove iron and aluminum while potential metals of commerce are still largely in solution. These metals are then removed by sulfide precipitation.

Product Waste Characteristics. Sulfide precipitation would not reduce the calcium or sodium content of the product water. In fact, if sodium sulfide was used, the sodium content would increase. The use of a first-stage lime treatment would increase the calcium content. As in the case of straight lime precipitation, these substances, along with the associated anions, would limit the use of the product water.

Sludges and Sidestreams. The sulfide precipitation process produces sludges primarily in a metal sulfide form. Care must be taken to ensure that the sludges are not allowed to oxidize in an uncontrolled manner as oxidation releases the metals as sulfates. Acidification of the sludges would have a similar result with the concurrent production of

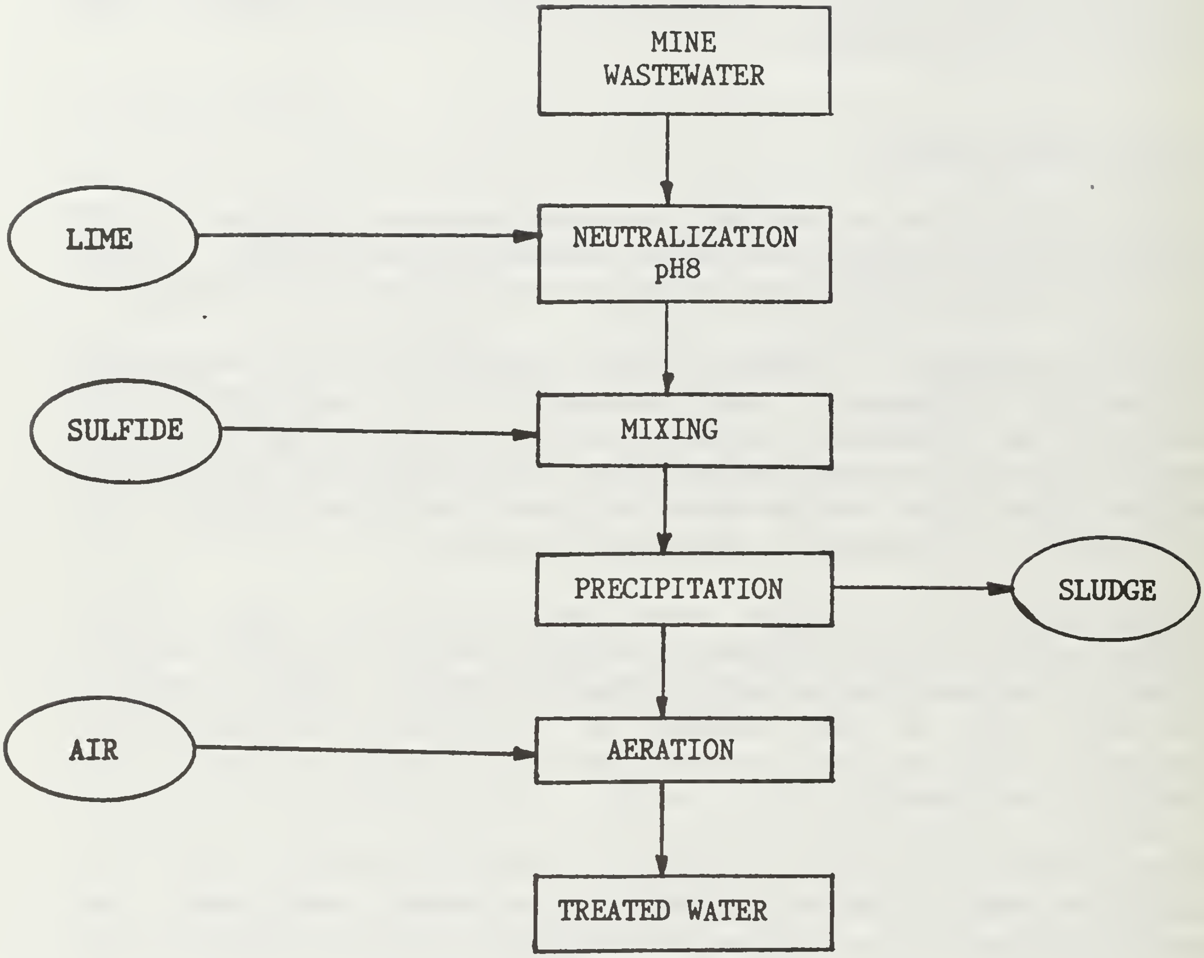


FIGURE 2.
SULFIDE PRECIPITATION

toxic hydrogen sulfide gas. Of course, controlled release of the sludge's metal content could be incorporated into a metals recovery scheme.

Advantages and Disadvantages. The sulfide precipitation process is a very effective metals removal technique that can be accomplished at lower pH levels with less base consumption. The process poses significant operator safety hazards and, therefore, requires much more careful and sophisticated instrumentation and controls. The process does not reduce the total dissolved solids content of the water.

Ion Exchange

Several variants of the ion exchange process have been successfully used to treat acid coal mine drainage and to reclaim heavy metals from industrial plant discharges. (Office of Saline Water, 1974) The process is also extensively used in hydrometallurgy, particularly in the uranium, silver, and gold industries. (Clark, 1974) Lack of application in the base metals industries has primarily been due to economics.

Process Description. A schematic flow diagram for a mine wastewater treatment system incorporating ion exchange is presented in Figure 3. The illustrated system is one that has been used to remove acid and heavy metals from coal mine drainage water with the objective of producing potable water. The process is essentially one of partial demineralization, followed by oxidation, filtration, and pH adjustment. Pretreatment to remove turbidity can be necessary. (EPA, 1978)

Strong acid cation exchangers are used to remove most of the cations. Calcium, sodium, and magnesium are removed as well as heavy metal ions. When the ion exchange resins are exhausted, the units are first backwashed (mine wastewater could be used) and then regenerated using a strong acid.

Weak base anion exchangers are used to remove mineral acids present in the wastewater. These exchangers are regenerated using a strong caustic.

The product of the anion exchangers can contain excessive amounts of iron and manganese. These metals are removed by adjusting the pH to about 10 and aerating the wastewater to oxidize the metals. The precipitated metals are removed by filtration and the water is neutralized prior to discharge.

The process is capable of essentially complete removal of dissolved solids, including heavy metals. It can be designed for a wide range of removal effectiveness. Treatment cost increases with removal efficien-

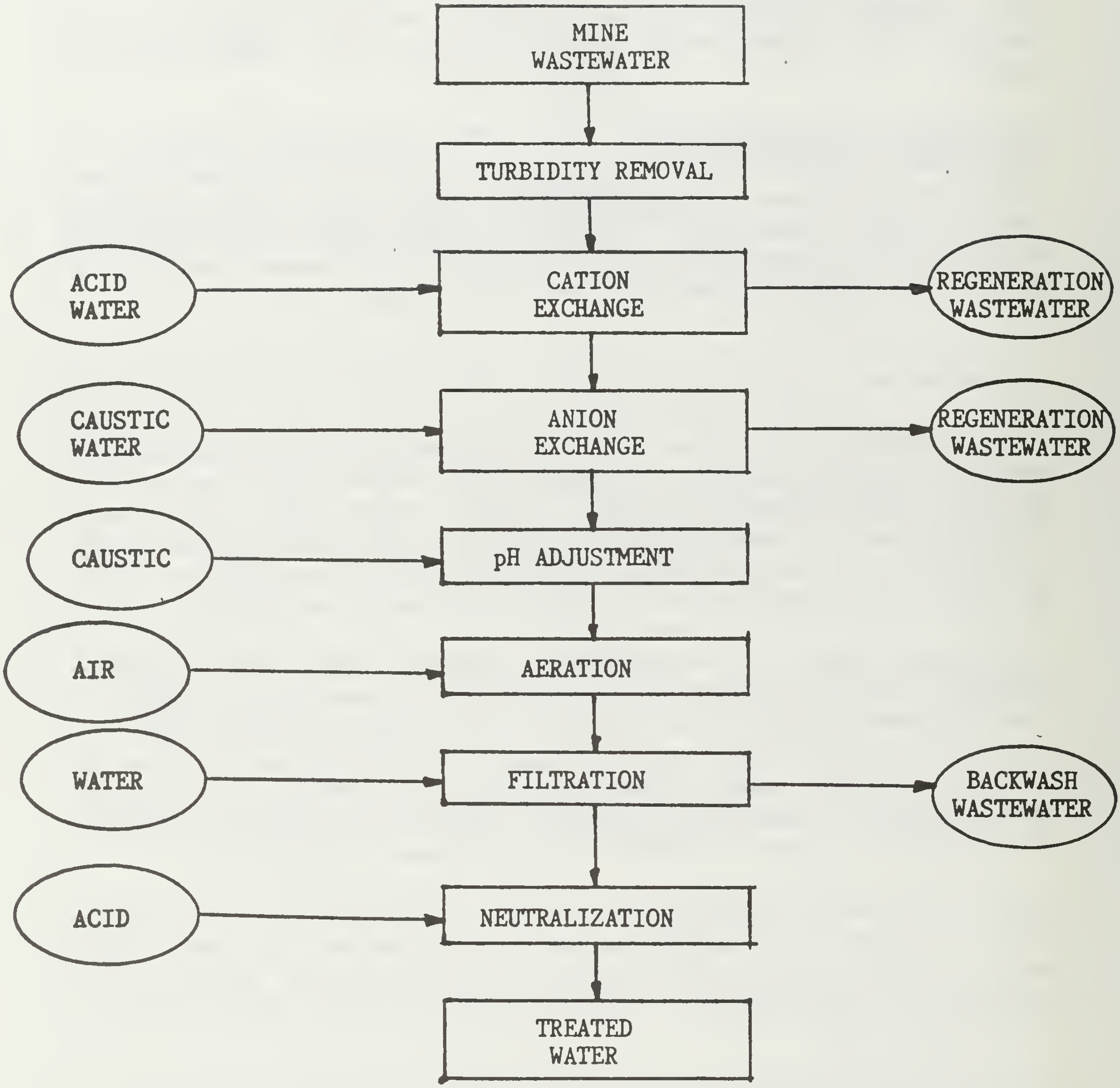


FIGURE 3.
ION EXCHANGE

cy. Although mine wastewater can be used for backwash, relatively pure acids and caustic are required for resin regeneration. Ion exchange resins are also lost during use and must be replaced. Natural ion exchange resins (zeolites) that might find use in the process are known to exist in Montana.

Product Water Characteristics. The product water stream should be essentially deionized water. Because water of this purity is seldom needed or desired, part of the pit water could be bypassed and blended with the deionized water to constitute a water of acceptable quality.

Sludges and Sidestreams. The process produces liquid sidestreams that comprise about 10 to 15 percent of the treated wastewater volume. The cation exchanger regeneration waste streams contain high concentrations of metals salts as sulfates or chlorides.

Advantages and Disadvantages. A primary advantage of the ion exchange process is its production of a concentrated liquid waste stream that contains metals of commercial interest and a product water of excellent quality. The primary disadvantage of the system is its cost. It may also be difficult to pretreat the mine wastewater for turbidity removal without increasing its pH, hence precipitating valuable metals. Precipitation of iron in the resin beds can also reduce the efficiency of this process.

Reverse Osmosis

Like ion exchange, reverse osmosis has been used to treat acid drainage from coal mines and to reclaim metals from industrial wastewaters. In reverse osmosis, pressure is applied to the more concentrated solution side of a semi-permeable membrane causing the permeate (in this case, water) to diffuse through the membrane. A concentrated solution of dissolved solids is left behind and is discharged as waste.

Process Description. A schematic flow diagram for the reverse osmosis process is presented in Figure 4. Reverse osmosis has a low tolerance for solids suspended in the input stream. Typically, pretreatment, in terms of coagulation and at least two stages of filtration, is required. Separation of pollutants involves their concentration in a liquid stream which may facilitate the recovery of metals and minerals. Reverse osmosis has been demonstrated to have the capability of removing heavy metals from wastewaters with a high degree of efficiency. Typical removal (rejection) percentages are as follows: (EPA, 1974)

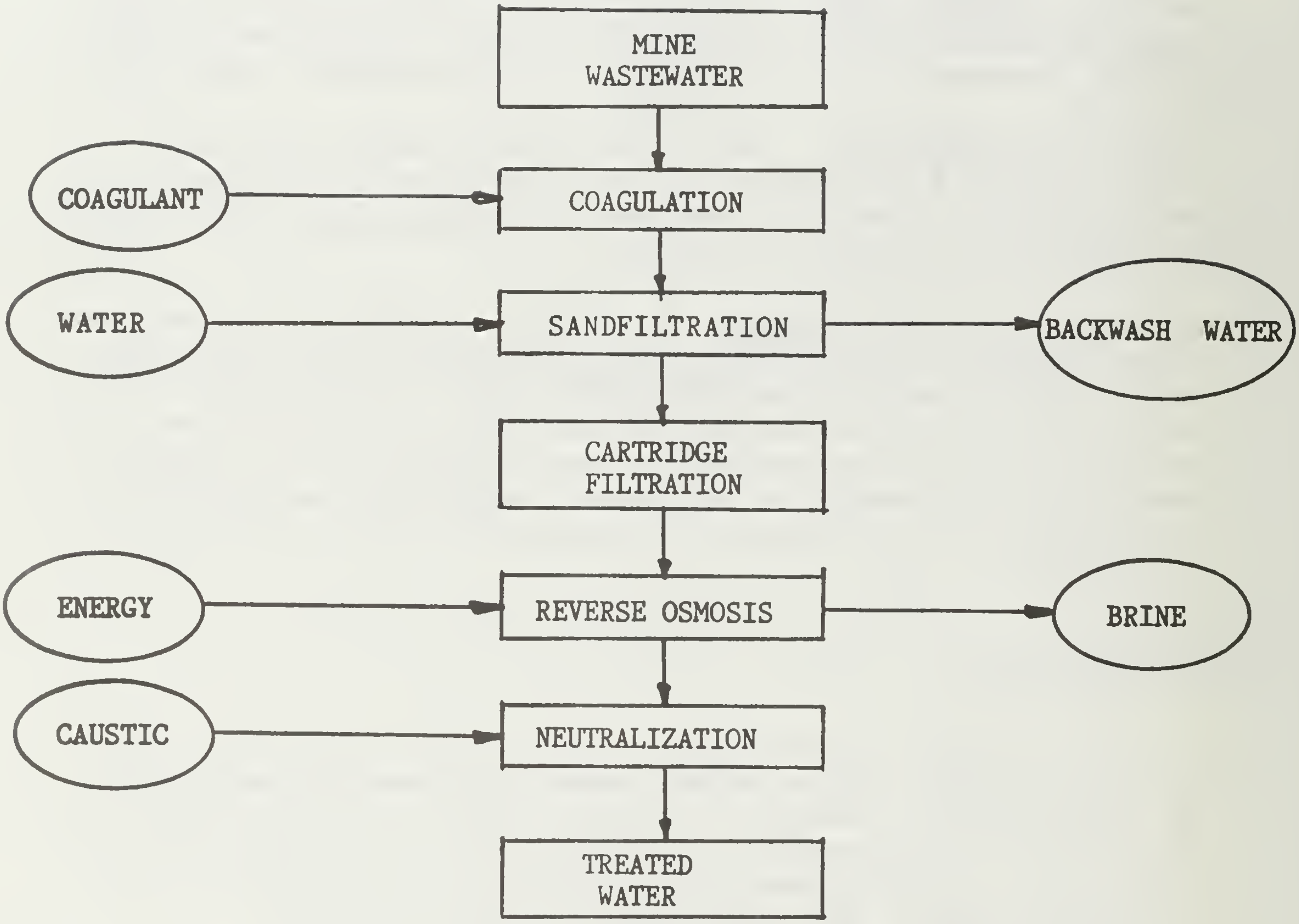


FIGURE 4.
REVERSE OSMOSIS

Metal	Rejection Percentage
Iron	99
Copper	99
Nickel	99.2
Silver	96

During the last decade, new low-pressure, thin-film composite reverse osmosis membranes have been developed that have definite advantages in terms of energy savings and pretreatment requirements. The spiral-wound reverse osmosis models containing thin-film composite membranes are much less prone to clogging than hollow-fiber modules. Also, thin-film composite membranes can be operated over a much wider pH range (typically 4 to 12), allowing, in some applications, less neutralizing chemical use. (Larson and Freeman, 1984)

Product Water Characteristics. Some leakage of metals and minerals through the membranes occurs. The product water quality can be controlled at a desired level by placing reverse osmosis units in series.

Sludges and Sidestreams. The reverse osmosis process can produce a liquid waste stream that contains essentially all (95-99 percent) of the metals and salts in its feed. These materials are contained in a concentrate that typically comprises 10 to 20 percent of the volume of input to the process. The metals are present in the same forms that are fed into the unit and can be further concentrated and recovered using such techniques as precipitation or cementation.

Advantages and Disadvantages. Some of the advantages of the reverse osmosis process include its ability to concentrate dilute solutions of metals and minerals and to sufficiently purify water for reuse. Disadvantages include limits on feed water temperature, pH, and solids content. High levels of calcium sulfate in the feedwater (which is the case here) can also result in membrane scaling at high water recovery levels.

Data currently available does not quantify the turbidity in the pit water. From visual observation, however, there is some turbidity, as would be expected due to the extensive contact between the water and the surface in the shafts and in the pit walls and bottom. Caving of the sides into the water would also result in the suspension of colloidal-sized particles that remain suspended in the water.

Turbidity has an adverse effect on the removal of dissolved metals and minerals by all of the processes described previously. Co-precipitation of turbidity with metals by the high pH lime process would almost certainly occur. Whether this material would, when mixed with the metal hydroxides, interfere with metals recovery is not known. Additionally, turbidity in the feed water to ion exchangers coats the resins and decreases the efficiency of the units. Finally, all suspended particles must be removed prior to membrane filtration in the reverse osmosis process.

Turbidity removal is a well understood and well documented operation in water treatment technology. The special circumstances encountered in the pit water offer both assets and liabilities in turbidity removal. As an example, aluminum and ferris salts are often used to coagulate turbidity to enhance its removal. These metal cations are present in more than sufficient quantity to accomplish this. Missing are the hydroxide ions necessary to precipitate these metals as aluminum hydroxide and ferric hydroxide. Addition of lime sufficient to raise the pH to approximately 5.0 should result in the precipitation of these metals as hydroxides, thus incorporating the turbidity in a floc sufficiently heavy to settle. Filtration should remove any leftover particles and produce a clear water with the remaining metals still in solution.

Other possibilities would include conditioning the turbidity with synthetic organic polymers just prior to filtration. Some commercially available polymers are effective down to a pH of about 3.0 just prior to filtration.

Effective turbidity removal depends upon many variables and the processes must constantly be adjusted to account for fluctuation in water and turbidity characteristics. Selection of the best chemical and the proper chemical dosage would have to be determined by pilot plant analysis.

POTENTIAL TREATMENT SCENARIO

Combinations of the above processes may be required to accomplish treatment objectives. Process selection should be based on the results of pilot plant and laboratory analysis, although some conjecture can be made at this point. Assuming that it will be desirable to treat the water to the point of compatibility with local surface and groundwater, a probable treatment scheme is shown in Figure 5. If the end use could tolerate water of lower quality, appropriate treatment processes could be eliminated.

CONCLUSIONS

The art and science of water treatment has developed to the point that virtually any water can be treated to the quality of potable water. Treatment processes are available that will selectively remove groups of contaminants that include turbidity, metals (both those with economic

Process	Primary Target Contaminant	Process	Product Stream	Waste Stream
1. Turbidity removal	Turbidity	Raise pH to 5.0 with lime flocculate, settle and filter	Clear water containing metals (except aluminum and iron) and minerals	Aluminum and iron hydroxide sludges containing turbidity particles
2. Lime or sulfide precipitation	Metals of economic value	Raise pH to 9.0 (if lime treatment) or add sulfide at pH 5.0, flocculate and settle	Water containing primarily calcium, and sodium, and sulfate (very hard water)	Hydroxides or sulfides and economic metals
3. Softening	Calcium (hardness)	Add soda ash, flocculate and settle	Water with low calcium but high sodium and sulfate	Calcium carbonate
4. Neutralization	High pH	Add acid	Same as above but approximately neutral pH	None
5. Filtration	Small metal flocs and calcium carbonate crystals	Filter	Clear water with sodium sulfate	Chemical sludge
6. Demineralizing	Sulfate and sodium	Use Ion exchange or reverse osmosis	High quality water	Concentrated sodium and sulfate solution

NOTE: Process 6 could possibly be used directly after process 1 and eliminate processes 2, 3, 4 and 5. This subsitution would depend upon being able to avoid calicum sulfate scaling of membranes in reverse osmosis system or the availability of appropriate ion exchange resins.

FIGURE 5.
EXAMPLE TREATMENT SCENARIO

value and those without), and minerals. These processes must be carefully chosen and executed to facilitate the recovery of materials.

The major factor involved in the treatment of Berkeley Pit water is economics. At this point, no attempt has been made to establish the cost of constructing and operating an appropriate facility, but it is reasonable that the cost would be significantly higher than the cost of providing comparable quality water from better sources. The degree to which this high treatment cost can be offset by the value of recoverable products is the key to project feasibility.

REFERENCES CITED

"Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Smelting and Slag Processing Segments of the Ferroalloy Manufacturing Point Source Category," U.S. Environmental Protection Agency, Washington, EPA-440/1-74-008a, February 1974.

"Development Document for Effluent Limitations Guidelines for the Ore Milling and Dressing Point Source Category," U.S. Environmental Protection Agency, Washington, April 1978.

"Evaluation of Ion Exchange Processes for Treatment of Mine Drainage Waters," Office of Saline Water, Envirex, Inc., Milwaukee, Wisconsin, PB-227734, January 1974.

Larson, R.E. and S.D. Freeman, "Industrial Application for RO and UF: Problems and Opportunities," National Well Water Association - Water for South Africa Exposition, Johannesburg, South Africa, November 12-17, 1984.

Robinson, A.K. and J.S. Sum, Sulfide Precipitation of Heavy Metals, U.S. Environmental Protection Agency, Washington, 600/2-80-139, June 1980.

"State-of-the-Art of Uranium Mining, Milling, and Refining Industry," Clark, D.A., U.S. Environmental Protection Agency, Washington, EPA-660/2-74-038, June 1974.

THE MINERALOGY OF THE ORES OF THE BUTTE MINING DISTRICT

By

Lester G. Zeihen

Montana Bureau of Mines and Geology

Dr. Lester Zeihen, now Associate Curator of the Minerals Museum at Montana College of Mineral Science and Technology, was formerly a Senior Mineralogist with the Anaconda Company.

INTRODUCTION

It has long been recognized that there was mineral zoning in the Butte Mining District. The fact would be obvious to any observer who recognized that the mines in the central to eastern part of the Butte district (e.g., the Mt Con, Kelley, Berkeley Pit, and Leonard) were copper mines; that the mines on the south to west (e.g., the Emma and Travona) were manganese mines; the mines to the west and north (e.g., Orphan Girl, Anselmo, Lexington, Alice, and Black Rock) were predominantly zinc mines, although producing some copper; and finally, most of the mines produced silver but the richest silver mines were on the west and north periphery of the district. (See Figure 1)

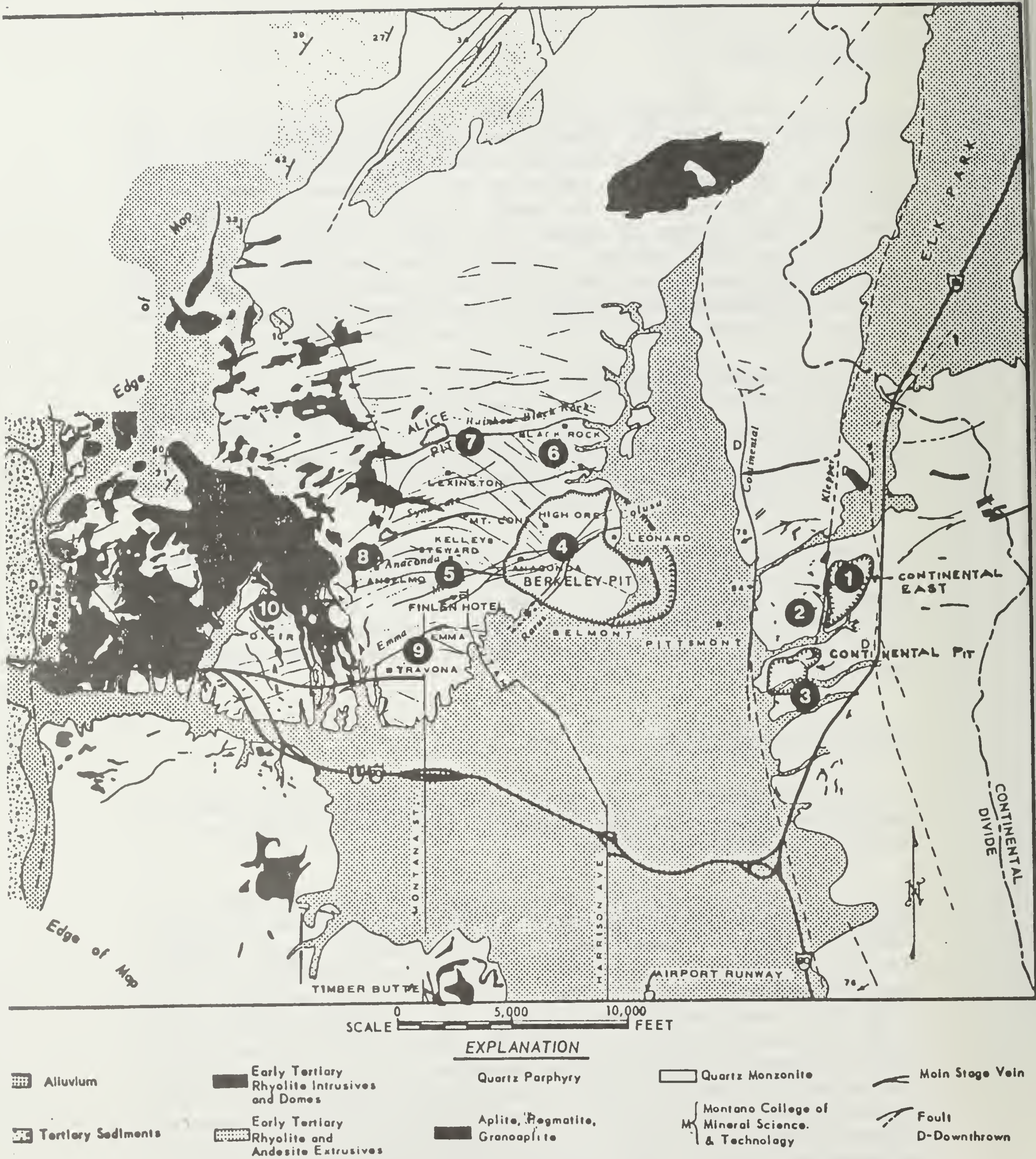
The first detailed description of mineral zoning was described by Reno H. Sales in 1914 in which he identified a Central Zone (copper), Intermediate Zone (copper to zinc), and Peripheral Zone (zinc, manganese, silver). The Berkeley Pit and Leonard mine are in the Central Zone; the Kelley, Mt Con, and Anselmo mines in the Intermediate Zone; and the other mines in the Peripheral Zone.

The continuing mining, development, and exploration of the ore bodies resulted in delineations of the zonation becoming much more precise as described in some detail by C. Meyer et al., 1958, pp. 1395-1403. These developments illustrated a vertical zoning as well as a horizontal one in that zinc mines encountered copper ores at depth, especially in the Anselmo area.

DETAILED MINERALOGY

A detailed mineralogy of ores found in the numbered zones as shown on the attached generalized map (Figure 1) of the Butte District is summarized in the following section.

No. 1. The East Continental Pit's primary mineralogy consisted principally of disseminated pyrite (iron sulfide), minor chalcopyrite (copper-iron sulfide), some small pyrite-sphalerite (zinc sulfide), rhodochrosite (manganese carbonate) veins and veinlets, and minor quartz-molybdenite veinlets. There were no arsenic minerals in this assemblage. Weathering caused oxidation of the sulfides which because of the presence of pyrite, resulted in strong acid conditions in this zone and prevented precipitation of secondary oxidized copper minerals. The copper is therefore leached from the rock leaving rusty to black iron-manganese stained waste rock down to the water table. Below this oxidized zone is the Supergene Zone where the copper was precipitated as secondary chalcocite and covellite (copper sulfides) on pyrite and replaced chalcopyrite. This action resulted in upgrading the primary mineralization (protore) to ore grade. Part of the copper from the



GENERALIZED MAP OF THE BUTTE DISTRICT

FIGURE 1

oxidized zone is lost into the groundwater and migrates to be deposited elsewhere or remains in very dilute solution to ultimately contribute to the copper content of the oceans. The waste rock of the oxidized zone has only traces of copper, zinc, or molybdenum remaining.

The above process is generally applicable to the near surface oxidation from a depth of a few feet to as much as five hundred feet (averages about 250 feet), depending on fracturing and mineralization of the rock over the area of the Butte district.

As there were no old underground workings in the volume of the East Continental Pit, no post-mine oxidation is present.

No. 2. The northern extension of the Continental Pit is now being stripped in preparation for mining. This is the area of the old Bullwhacker Pit. The primary ore minerals were disseminated chalcopyrite with minor pyrite and a few small quartz-chalcopyrite veins. In the oxidized zone of this area, however, the lack of pyrite causing lower acid conditions resulted in the precipitation of oxidized copper minerals such as chrysocolla (copper silicate), azurite and malachite (copper carbonates), cuprite and tenorite (copper oxides), and native copper. The concentrations of these minerals in shear zones and minor vein loci were responsible for the small Bullwhacker Pit. There is also a weakly secondarily enriched Supergene zone which is mixed in with the lower portion of the oxide zone and is now about to be mined. This zone also contains the quartz-molybdenite-pyrite veinlets and stringers in greater concentration than in No. 1 above. No arsenic-bearing minerals have been identified from this zone.

No. 3. The southern part of the Continental Pit and the former location of the Butte-Duluth Pit has similar mineral characteristics to the Bullwhacker. The oxidized zone ore minerals occurred at varying depths (less than 100 feet), depending on groundwater access involved with larger veins and fault planes. The Supergene zone shows chalcocite enrichment by replacement of chalcopyrite and deposition on minor pyrite. Minor amounts of covellite are also involved in this process. The primary mineralization is the same as that in areas No. 1 and No. 2 described above except that there is minor bornite in some of the veins. Quartz-molybdenite veinlets and disseminated chalcopyrite are responsible for the economic possibilities of this zone. No arsenic-bearing minerals have been identified.

No. 4. The Berkeley Pit includes the Central Zone and parts of the Intermediate Zone of Sales. The Central Zone is distinguished by pervasive sericitic (white mica) alteration of the rock. The primary vein mineralogy is composed of copper minerals and is free of zinc and manganese minerals, the principal gauge minerals being abundant pyrite and quartz. The predominant copper minerals are chalcocite with minor exsolved bornite (copper sulfides), enargite (copper sulfarsenide), covellite (copper sulfide), minor digenite (copper sulfide), and traces of colusite (a rare copper-tin-vanadium-iron sulfarsenide) and wittichenite (copper bismuth sulfide). The veins and veinlets are closely spaced and the intervening rock is strongly pyritized.

Surrounding this central copper zone with irregular boundaries and extended outward by major veins is the Intermediate Zone where rock alteration is predominantly argillic, the primary copper ore mineralogy changes to bornite, chalcopyrite, tennantite (copper sulfarsenide), and minor chalcocite and enargite in the sulfide veins of this zone. In this zone zinc is present as sphalerite (zinc sulfide) with minor local galena (lead sulfide) in increasing amounts away from the Central Zone. Trace amounts of digenite, covellite, colusite, wittichenite, stromeyerite (copper-silver sulfide), heubnerite (iron-manganese tungstate) and scheelite (calcium tungstate) are also present. The top of the dome-shaped body of the quartz-molybdenite veinlet mineralization lies some two thousand feet below the surface principally to the west of the Berkeley Pit in the Belmont, Kelley, and Mt. Con mines. The original leached capping over the Berkeley Pit area averaged about 250 feet. Because of the very pyritic nature of the mineralization in this area, no secondary copper minerals could precipitate during weathering, and the copper values left were measured in a few hundredths of a percent. The Supergene Zone of secondary enrichment was very irregular at the bottom, varying in thickness from about a hundred to over seven hundred feet. Secondary chalcocite and some covellite are the minerals that replaced bornite, chalcopyrite, enargite, sphalerite and coated pyrite. The large rich veins of the Berkeley Pit were mined out in underground mines previous to the opening of the pit. In this zone, therefore, circulating surface waters caused post-mine oxidation in the wall rocks, and old gob (vein) fillings resulted in the deposition of water-soluble minerals such as chalcanthite (acid copper sulfide), goslarite (zinc sulfate), and many iron sulfates. These minerals contributed to the so-called "sour ores" which plagued the metallurgists at the concentrator.

No. 5. The ores are in the Intermediate Zone, as noted above, in which the primary mineralogy of the large Anaconda east-west vein systems changes from the Central Zone to the Peripheral Zone with increasing amounts of sphalerite being encountered and chalcopyrite becoming the principal disseminated copper mineral in the rock between the veins. Supergene enrichment of the upper parts of the large veins of this volume resulted in the spectacular ore bodies mined during the early years of the District.

No. 6. This volume represents the transition between predominantly copper ores to predominantly zinc ores. In the north side of the Berkeley Pit an increasing percentage of sphalerite was encountered, and farther to the north at the location of the Badger State (copper), Black Rock and Elm Orlu mines, predominantly zinc ores were mined. Some of the veins were closely spaced and with added disseminated minerals produced volumes suitable for block cave mining of zinc ore. Pyrite was not as prominent in these mines as in those to the south and west. In addition to sphalerite there was rhodonite, rhodochrosite, some galena (lead sulfide), silver minerals such as native silver and acanthite (silver sulfide), primary copper minerals such as chalcopyrite and bornite with secondary chalcocite in the Supergene Zone.

No. 7. The Alice Pit (old Alice Mine) is on one of the principal east-west vein systems (Alice-the Rainbow-Black Rock system). The mines in this area are in the Peripheral Zone. The primary mineralization consists of quartz, rhodonite (manganese silicate), rhodochrosite, some pyrite, silver minerals such as native silver, acanthite, etc., sphalerite, and very minor chalcopyrite. In the oxidized zone, the silver minerals are replaced by cerargyrite (silver chloride). The rock between the veins is weakly altered and essentially unmineralized.

No. 8. The Anselmo Mine is located on the western extension of the Syndicate and State veins. The primary ore mineralization in the upper levels is sphalerite with some chalcopyrite and bornite, minor chalcocite and tennantite and silver minerals including stromeyerite (copper-silver sulfide). At lower levels, the sphalerite decreases to a trace with a corresponding increase in chalcopyrite. There are also traces of rhodochrosite.

No. 9. The Emma and Travona mines are located on the Emma vein system, the southernmost of the great east-west vein system of the Butte District. This is in the Peripheral Zone on the southwest side of the district. The primary ore mineralization was rhodochrosite with quartz and minor pyrite and sphalerite in the upper levels. The lower levels and eastern ends of the veins contain more sphalerite, minor chalcopyrite and silver mineralization. On the west end, the veins are cut by a post-mineral rhyolite dike which locally developed some alabandite (manganese sulfide). Greenockite (cadmium sulfide), a rare mineral for Butte, was also identified coating sphalerite. It should be noted that no rhodonite was ever identified from these ores although it is a common mineral on the north side of the district. In the oxidized zone, the veins are very siliceous with the rhodochrosite being converted to manganese oxides such as pyrolusite and cryptomelane.

No. 10. The Orphan Girl, Orphan Boy, Nettie, Norwich, and Bluebird mines (east to west) are in the Peripheral Zone on the westward extension of the east-west vein zones between north-south rhyolite dikes and bodies. The primary mineralogy of the eastern mines is predominantly quartz, pyrite, rhodonite, rhodochrosite, silver minerals, and sphalerite with the manganese minerals decreasing with depth and the sphalerite increasing to form zinc ores. The Bluebird Mine, the westernmost of the Butte District, is only credited with silver ore. In this mine the zone of oxidation extends to a depth of 200 feet and the vein consists of quartz, manganese oxides, and silver minerals, predominantly cerargyrite, with minor native silver.

The large waste and leach dumps filling the valley north of the Berkeley Pit contain a composite of ore minerals from the Berkeley Pit mining operation. The oxidation of these minerals may contribute a number of trace elements to the solutions other than the common ones such as copper, zinc, iron, arsenic, sulfur, lead, and manganese. Among these are bismuth which is found in wittichenite and aikinite; antimony in tennantite-tetrahedite, pyrargyrite, pearceite, stephanite, and audorite; tungsten in scheelite, huebnerite and ferberite; uranium in uraninite(?), cadmium in greenockite, tellurium in tennantite, vanadium in colusite, tin in colusite, indium in sphalerite, germanium in enargite, colusite(?), and tennantite(?). Traces of uranium were identified by scintillator and chemical analysis, associated with a light brown stained quartz, by the Atomic Energy Commission (AEC) during the war years. One occurrence of autunite was identified in a specimen of manganese oxide ore from the Norwich Mine west of the Orphan Girl.

In abandoned mine workings throughout the district above the water table, secondary minerals from groundwater circulation are precipitated as stalagmites in large mine openings and in fillings of cavities of waste back-filling in old stopes and crevasses adjacent to mined veins. These are largely water-soluble sulfates of copper (chalcanthite), of zinc (goslarite), and of a large series of iron sulfates (coquimbite, copiapite, roemerite, etc.). Under certain conditions, a water-soluble molybdenum mineral ilsemanite (hydrous molybdenum oxide) may form. It should also be noted that under certain reducing conditions, especially in "fire zones," old mine timbers are impregnated with metallic copper. Iron and steel objects such as mine rails, pipes, tools, etc. are also replaced by metallic copper.

APPENDIX

Glossary of Mineral Names and Chemical Formulae.

ACANTHITE Ag_2S
(Argentite)
AIKINITE $PbCuBiS_3$
ALABANDITE MnS
ANDORITE $PbAgSb_3S_6$
AUTUNITE $Ca(UO_2)_2(PO_4)_2\cdot 10\text{-}12H_2O$
BORNITE Cu_5FeS_4
CERARGYRITE $AgCl$
CALCANTHITE $CuSO_4\cdot 5H_2O$
CHALCOCITE Cu_2S
CHALCOPYRITE $CuFeS_2$
COLUSITE $Cu_3(As,Sn,V,Fe)S_4$
COPIAPITE $Fe_5(SO_4)_6(OH)_2\cdot 20H_2O$
COPPER Cu
COQUIMBITE $Fe_2(SO_4)_3\cdot 9H_2O$
COVELLITE CuS
CRYPTOMELANE KMn_8O_{16}
DIGENITE Cu_9S_5
ENARGITE Cu_3AsS_4
FERBERITE $FeWO_4$
FERRIMOLYBDITE $Fe_2(MoO_4)_3\cdot 8H_2O$(?)
GALENA PbS
GOLD Au
GOSLARITE $ZnSO_4\cdot 7H_2O$
GREENOCKITE CdS
HEMATITE Fe_2O_3
HUEBNERITE $(FeMn)WO_4$
ILSEMANNITE $Mo_3O_8\cdot nH_2O$(?)
LIMONITE (Mixture of hydrous iron oxides)
MAGNETITE Fe_3O_4
MOLYBDENITE MoS_2
POLYBASITE $(Ag,Cu)_{16}Sb_2S_{11}$
PYRARGYRITE Ag_3SbS_3
PYRITE FeS_2
PYROLUSITE MnO_2
QUARTZ SiO_2
RHODOCHROSITE $MnCO_3$
RHODONITE $(Mn,Fe,Mg,Ca)SiO_3$
ROEMERITE $Fe_3(SO_4)_4\cdot 14H_2O$
SCHEELITE $Ca(W,Mo)O_4$
SILVER Ag
SPHALERITE ZnS
STEPHANITE Ag_5SbS_4
STROMEYERITE $CuAgS$
TENNANTITE $Cu_{12}As_4S_{13}$
TETRAHEDRITE $Cu_{12}Sb_4S_{13}$
URANINITE UO_2
WITTICHENITE Cu_3BiS_3

Chemical Symbols for Elements

Ag = silver
As = arsenic
Au = gold
Bi = bismuth
Ca = calcium
Cd = cadmium
Cl = chlorine
Cu = copper
Fe = iron
H = hydrogen
In = indium
K = potassium
Mn = manganese
Mo = molybdenum
O = oxygen
P = phosphorus
Pb = lead
S = sulfur
Sb = antimony
Si = silicon
Sn = tin
Te = tellurium
U = uranium
V = vanadium
W = tungsten
Zn = zinc

REFERENCES CITED

Meyer, C., E.O. Shea, C.C. Goddard, Jr., and Staff, 1968, "Ore Deposits at Butte, Montana" in Ore Deposits of the United States, American Institute of Mining Metallurgical & Petroleum Engineers, New York, pp. 1373-1416.

Sales, R.H., 1914, "Ore Deposits at Butte, Montana," Trans. American Institute of Mining Engineers, v. XLVI, pp. 3-109.

Society of Economic Geologists, U.S. Geological Survey, The Anaconda Company Geological Department, 1973: Guidebook, Butte Field Meeting August 18-21, p. 109, plate 64.

Weed, W.H., 1912, "Geology and Ore Deposits of the Butte District, Montana," U.S. Geological Survey Prof. Paper 74, p. 262.

A REVIEW OF BUTTE METALLURGY

By

William R. Stern

Prototech, Inc.

Mr. William Stern, representing Prototech, is formerly Senior Metallurgist for the Anaconda Company.

AUTHOR'S NOTE

This paper is presented as an action paper to form a basis for discussion for the Expanded Steering Committee Meeting of HRI in Butte in January, 1987. It is not intended or pretended to be a thoroughly researched, footnoted work in the scientific sense. Anaconda's Research Department records are no longer available and much of this was done from memory.

FORWARD

This was a difficult paper to organize. After several false starts, I came to the conclusion that the subject had to be treated with a historical perspective, and that it had to involve geology and mining as well as metallurgy.

Where geology and mining are discussed, it is with the viewpoint of a metallurgist -- a more-or-less well informed observer rather than an expert. In geology, in particular Dr. Zeihen's paper, I am sure, will be both more comprehensive and far more authoritative.

The theme has been developed to emphasize the economic factors which led to various decisions and developments. In hindsight, some of these may have been faulty, but a knowledge of these decisions is essential to understanding what happened.

The opinions expressed (and they are many) are personal. They do not necessarily express a corporate viewpoint, past, present, or future.

GEOLOGICAL DEFINITIONS

For those who have little or no background in geology, a few (I hope very few) definitions are in order. These definitions with some elaboration area:

1. Minerals are inorganic chemical elements or compounds found in the earth's crust. Examples of elemental minerals are gold, silver, mercury, sulfur, etc. Much more plentiful are compounds, examples of which might be:

Quartz	SiO_2
Chalcocite	Cu_2S
Chalcopyrite	$CuFeS_2$
Pyrite	FeS_2

Minerals are classified by the nature of their non-metallic components, i.e., as native minerals, oxides, carbonates, sulfates, sulfides, phosphates, etc.

A special classification, which is really more due to metallurgical behavior than to logical chemical coding, has developed for copper minerals. There are two groupings, sulfides and oxides, with the oxide grouping including true oxides, native copper, carbonates, sulfates, silicates, and chlorides.

Under this definition, water is also classified as a mineral, and was so recognized in early mining law to the extent that water developed in the course of operating a mine belonged to the mine owner until such time as he turned that water into a public stream. Before that event he could use the water as he saw fit. The corollary, of course, is that he is responsible for damages if the water so developed harms a public stream.

2. Rocks. A rock is a heterogeneous mixture of minerals found in the earth's crust. There are three main types of rock: a) sedimentary, b) igneous, and c) metamorphic. Only igneous rocks need concern us in this study and not to a very great extent.

The classification of igneous rocks is incredibly complex, and requires both chemical analyses and petrographic studies after which two well qualified geologists may differ. In general, the classifications are based on silica content and on grain size, whether fine grained, coarse, or a mixture of grain sizes. A rock high in silica (SiO_2) is said to be acidic; one low in silica is basic. These terms have little if any relation to the chemical meanings of these terms. They were developed by the earth nineteenth century geologists whose basic training was in chemistry, and who considered SiO_2 to be the anhydride of silicic acid.

3. Mineral Resources. A mineral resource is a substantial occurrence in the earth's crust of rocks containing minerals of commercial value.

4. Ores. An ore is a mineral resource which can be mined and treated at a profit.

That last definition is the crux of the matter in the mining industry. Butte has mineral resources which may be measured in billions of tons. Hopefully the Continental Pit of Montana Resources Company is now mining ore. Only their profit and loss statement will determine whether this is true.

Note, also, the classification of a mineral resource will vary with the price received for the products mined and treated, and with the capital and operating costs required for exploitation of the deposit. Changes in labor or power costs, taxes, interest rates, etc. can increase or decrease the value of reserves by very substantial amounts.

GENERAL DESCRIPTION OF BUTTE GEOLOGY

The present Rocky Mountains were built in late Cretaceous time by a tremendous geologic cataclysm known as the Laramide Orogeny or Laramide Revolution. Either very late in this event or shortly thereafter, the Boulder Batholith (a massive breakout of molten rock covering approximately 1,000 square miles) occurred. Butte is within but near the southern edge of this batholith. After solidification, the rock, locally known as "Butte Granite" but more properly classified as a quartz monzanite, became the host rock for the Butte ore deposits.

As the rock cooled and solidified, vertical fissures or fractures developed. Ascending highly mineralized high temperature waters (known as juvenile or plutonic waters) deposited minerals as they cooled, thus forming the very rich Butte veins. - Actually there were three distinct periods of fissuring and also three or four periods of major faulting (slippage of one mass of rock against another) causing the extremely complicated vein system of the Butte district. Each of these occurrences resulted in vein formation of economic importance.

Later still, after major vein formation had ceased, a rhyolite dike (a dike, like a batholith, is an intrusion of molten rock, but one of its horizontal planes is narrow) formed what is the present Big Butte and the bench on which Montana Tech sits, and separated the westernmost part of the ore body from the main district as exemplified by the Orphan Girl and Nettie mines.

At a period also later than that of vein formation and possibly much later, a tremendous faulting action occurred forming the Continental fault. The upthrust was of several thousand feet in magnitude and produced the Continental body now being mined by MRC. There will be more on this later.

Butte ore mineralization occurred in a zonal arrangement. Visualize three very irregular concentric ovals in a plan view with the long axis in an east-to-west direction. The valuable minerals in the central zone are almost entirely copper minerals with substantial silver values. In the intermediate zone, there is a gradual decrease in copper content and increasing amounts of zinc, lead, and silver until they become the minerals of predominant value. This gradual change persists into the peripheral zone where copper is nonexistent, lead and zinc lessen but are still important, and the principal value is silver. Also in the southwestern mines such as the Emma and Travona, manganese occurring as rhodochrosite ($MnCO_3$) was of great value, both economically and as a vitally important strategic mineral in both World Wars.

It should be noted that the central or copper zone expands with depth. The Badger Mine in the northeast and the Anselmo far to the west near Excelsior Street were very rich lead-zinc-silver at shallow depths (down to about 2,000 feet) and good copper mines, although not the best because of narrower veins, at the 3,000-foot level.

I have not attempted to list the minerals of importance at this place; they are listed for reference at the end of this paper. However, it is necessary to mention what happens at great depths. Below 4,000 feet the veins persist but the host or "country" rock changes. Instead of being barren, it is disseminated almost uniformly with chalcopyrite ($CuFeS_2$) and to a lesser extent with molybdenite (MoS_2). These are the minerals being mined in the Continental Pit, and they are there because of the tremendous upthrust of the Continental fault mentioned previously.

EARLY MINING AND METALLURGICAL HISTORY

Mining in the Butte area started as placer gold mining centered first at the village of Silver Bow about seven miles west of Butte and proceeding upstream along the creek and the northward gulches: Missoula Gulch (about where Clark Street now is) and Town Gulch (now Dublin Gulch). The placers, while profitable, did not approach the richness of the great gold camps of Bannock, Virginia City, and Helena, and were soon exhausted.

Attention was soon given to the manganese-stained quartz outcrops, still so prominent to the west and north of Butte. They proved to be rich in silver and at this very early period, about 1875, Butte mining development turned capital-intensive. It should be borne in mind that the men who first located and attempted to work these hard rock deposits were not the proverbial prospectors with pick, shovel, gold pan, and jackass. They were experienced miners of moderate means, able to live without outside income for several years and to attract some outside financing (today we would call it venture capital) from such early mining barons as Hearst, the Walker Brothers and other Salt Lake interests, the Helena gold millionaires and wealthy Montana merchant-bankers such as Clark, Larrabie, and Broadwater.

The complex nature of the Butte mineralogy made it self-evident that metallurgical treatment would be required to produce a product rich enough to ship. Several small reduction plants were built, all of them complete failures. The operators drew on Comstock experience where only crushing and amalgamation were required, and on Utah practices of reduction smelting followed by volatilization of the lead (a large-scale application of the fine assay). Smelting to produce a high-grade matte (a mixture of metallic sulfides) was tried but failed because of lack of knowledge of methods of fluxing to remove undesirable elements as a slag.

We read of early Butte ore being so rich that it was hauled by ox cart to Utah, shipped by rail to Baltimore and then by sea to Swansea, Wales, and that it still yielded a profit. This happened, as did lesser known shipments by cart to Fort Benton and then by river steamboat and rail to New Jersey. These events did occur, but the shipments were of hand-picked, very rich ore, the rest being stockpiled. The revenue was welcome, but the primary purpose was to let some of the world's most experienced metallurgists devise methods of treatment.

In the meantime, similar difficulties were encountered in Colorado. The Guggenheims and others took an opposite tack. Instead of exporting ore, they imported British and German metallurgists and developed what became known as the Colorado system. Essentially it involved heap roasting to control the sulfur content, melting in reverberatory furnaces to produce a matte, and use of Bessemer converters, originally invented for steel production, to produce a blister copper (impure metallic copper) containing the gold and silver.

This system proved satisfactory for Butte ores and turned Butte for a few years into the world's greatest silver camp. All of these developments occurred in a space of five or six years and without modern means of communication; contrast it with present lead times in mining and other industries.

The decade of the eighties resulted in revolutionary changes for Butte. The silver deposits in the central zone turned at relatively shallow depth to copper of previously unknown richness and size. The inventions of the telegraph, the telephone, and the electric light multiplied the demand for copper. The invention of electrolytic refining permitted production of copper of satisfactory purity. And finally, government action in 1892 in stopping free coinage of silver caused a severe depression in the silver camps of the West.

This is a convenient time to stop the general historical narrative and to discuss metallurgical developments in copper, zinc, and manganese separately, as well as a consideration of sulfur resources.

COPPER METALLURGY

Marcus Daly is commonly credited with being the first person to realize the significance of the Butte copper deposits. Whether or not this is true, it is certain that Daly, with, for his purposes, practically unlimited financial resources from the Hearst-Haggin-Tevis syndicate, was able to make Anaconda by far the largest operator in the district.

The other operators, Heinze, Clark, the Parrot interests, etc. built small smelters at Butte or, in the case of the Boston and Montana, at Great Falls. Boston and Montana selected Great Falls because they planned an electrolytic refinery to treat all the copper of the Butte district. In those days of low voltage power transmission, it was cheaper to ship copper rather than electricity.

Daly, because his much larger operations had a high water requirement, selected Warm Springs Creek, the present-day city of Anaconda, as the site for his operations. When concentration operations were moved to Butte in the early sixties, a pipeline was built from Anaconda to Butte to supply the Weed concentrator. If, when the time comes to treat Berkeley waters, milling operations are still being conducted in Butte, that treated water may have to meet only milling rather than potable standards.

In the period prior to the development of bulk flotation in 1914, ores were classified as first and second class. First-class ores contained more than 10 percent copper and were smelted directly in blast furnaces. Ores less than 10 percent copper had a mine cutoff of ± 4 percent depending on copper prices and operating costs, which varied from mine to mine and even to individual stopes. Rock which had to be mined in the course of mine development and which contained more than 2 percent copper was classified as "development ore" and was also treated.

These ores were concentrated by various gravity methods. The concentrates were roasted to control sulfur content, smelted to produce matte in reverberatory furnaces and blown to blister copper in converters. The copper was cast into anodes and sent to Great Falls for refining. With the consolidation of operations in Butte, all copper milling and smelting operations were moved to Anaconda. The Butte plants, with the exception of the Pittsmont Smelter, were shut down and dismantled.

Gravity methods of concentration result in a disproportionate loss of fines. This was particularly serious in the case of Butte ores because chalcocite, the most common mineral and the richest in copper, was also one of the softest and thus more easily abraded.

The development of bulk flotation in 1914 solved the problem of fines recovery to a great extent and led to the decision to do all smelting in reverberatories and converters. The blast furnaces kept operating through 1918 because of World War I demands, but were then shut down and dismantled. Also because of wartime demands much of the old gravity tailings were reclaimed and re-treated by flotation during both World War periods.

Bulk flotation floats all sulfides indiscriminately. The enhanced recovery of fines, the foreseeable shutdown of the blast furnaces, and the presence of pyrite as the predominant sulfide resulted in the construction of very large roasting and reverberatory plants.

The big stack at Anaconda was built at the same time. The reason commonly given for construction of the stack is pollution control and this was a consideration. In actual fact, the height and diameter of the stack were determined by the draft requirements of the new roasting and smelting plants. Incidentally, the brick for the stack and much of the refractory brick used over the years in the smelter were manufactured from slime tailings which are much higher in Al_2O_3 content than the sands. Is this an overlooked possibility for new industry in the Butte-Anaconda area?

The next major improvement was the development of selective flotation in 1927 permitting the rejection of pyrite. The results were startling. The roasters required dropped in number from 28 to 4, and the reverberatories from 8 to 2.

Little of note occurred until World War II when the Great Falls-type converters were replaced by Peirce-Smith types. The future use of the Great Falls converters will be described in the section on manganese.

The years immediately following the war saw very major changes. While deep-level mining of high-grade ore continues, the Greater Butte Project was instituted involving block-cave mining on a very large scale (40,000 tpd) in the upper sections of the mine. This resulted in a great enlargement of the Anaconda concentrator, the substitution of rod-mill ball-mill circuits for the rolls ball-mill grinding circuits, and the standardization on 50-cubic-foot Agitair flotation machines in place of the motley collection of cells in the old concentrator. Because the old mined areas had oxidized to an appreciable extent, the LPF or leach-precipitation-float process was developed. This involved scouring of the ore prior to grinding in rubber-lined mills in the presence of sulfuric acid. The dissolved copper was precipitated with sponge iron which was made in Bruckner-type furnaces from iron oxide calcine resulting from roasting of pyrite to produce sulfuric acid. The precipitated copper proceeded with the ore stream and was recovered along with the sulfides in the flotation circuit.

The block-cave stopes were pulled until copper grade dropped to ±0.4 percent copper, depending on copper price. Some of the remaining unpulled rock can be seen on the north side of the Berkeley Pit, occasionally sloughing off into the water. I do not know how much of these block-cave remnants remain and how much has already been mined in the pit, but they could be a prolific source of dissolved copper if acidity and ferric sulfate concentrations are satisfactory.

The next major change was the decision to start open-pit operations and to move concentration operations to Butte, resulting in the construction of the Weed concentrator.

The Weed, built in the early sixties, was state-of-the-art at that time in many respects, particularly as regards automation. However, in two critical high-cost sections, grinding and flotation, a decision was made to install existing equipment from Anaconda using rod-mills, ball-mills, cyclones, and flotation cells. This resulted in these two sections in a design which represented best practice in the late forties. The Weed, therefore, must be considered to be the design of forty years ago, resulting in high operating and maintenance costs. To modernize the mill to conform to latest practice would involve an expenditure of $100 to $200 million, most likely toward the higher figure. Such a modernization would involve a semi-autogenous grinding circuit and the installation of very large flotation cells instead of the tiny 50-foot 3 cells now in use.

The selection of a Butte site also resulted in a very expensive tailings disposal system. Where most concentrators can dispose of their tailings by gravity, Butte was forced to pump these very abrasive pulps several hundred feet in elevation and a mile or more horizontally with consequent very high operating and maintenance costs. Disposal of the sand fraction of the tailings in the Berkeley Pit should result in major savings.

The start of open pit operations also resulted in the production of very large tonnages of overburden (waste rock not high enough in copper to justify conventional treatment). This made possible the large dump leaching operations which started at this time and which will be discussed later in the section on leaching.

The latest major change was the abandonment of the Berkeley Pit, the consequent decision to allow the mines to flood rather than try to continue deep mining, and the shift to the East Berkeley or Continental Pit, where MRC is now mining. As mentioned before, the mineralogy is much simpler; copper being present only as chalcopyrite, molybdenum as molybdenite (MoS^2) and with much lower silver values.

ZINC METALLURGY

Zinc in the early days was considered a nuisance, not recoverable and causing sticky slags in the copper operation.

About 1906, the Butte and Superior Mining Co. began treating the very rich ores of the Badger/Black Rock/Grey Rock area. The ores were concentrated by gravity; losses of lead and silver must have been atrocious because of the sliming tendency of galena. The concentrates were then shipped east to retort plants where the zinc was fumed off and the residue treated in lead smelters for lead and silver recovery.

The development of bulk flotation mitigated these losses and became the incentive for the development of the electrolytic zinc process simultaneously, but independently, by Anaconda and Consolidated Mining metallurgists. This made Butte and Consolidated's operations at Trail, British Columbia, the premier zinc mines of the world.

The electrolytic zinc process, from the standpoint of getting the squeal out of the pig, has to be one of the most elegant ever devised. All of the developments did not occur at once, of course, but the following processes resulted in the recovery of zinc, lead, copper, cadmium, gold, silver, platinum group metals, indium, gallium, and germanium. The necessity to roast the ores resulted in the production of large volumes of sulfuric acid, which in turn led to the development of the western phosphate fertilizer industry. Production of zinc continued up into the seventies, although in later years most of the feed was concentrates from producers in other areas.

MANGANESE METALLURGY

Manganese production had its start in World War I. The government-financed Domestic Manganese Smelter was built in South Butte and was fed from the very high grade massive rhodochrosite ($MnCO_3$) deposits of the Emma Mine. The product was MnO nodules which were shipped east to produce ferro-manganese for the steel industry.

Also, at this time, an idle copper converter in Great Falls was used to build an experimental electric ferro-manganese furnace. This work bore fruit much later.

Operations between the wars continued on an intermittent basis and the extremely pure high grade deposits which required no concentration were gradually exhausted. However, again due to the advent of selective flotation, processes were developed to float the lead and zinc minerals with accompanying silver followed by soap flotation to concentrate the rhodochrosite.

The impetus of possible wartime needs, beginning in 1940, led to the conversion of the Domestic Manganese plant to treat pyrolusite (MnO_2) ores from Philipsburg, Montana.

A much larger concentrator and a manganese nodulizing kiln were built in Anaconda and operated through the war.

The construction of the Peirce-Smith copper converters during the war idled the old "Great Falls"-type converters located in Anaconda. Four of these converters were changed to an electric furnace ferro-manganese plant and operated up into the sixties. At times, one or more of these furnaces were used to produce ferro-silicon.

The advent of the South African plants pretty much sounded the death knell of the American ferro-manganese industry. With massive steam coal and manganese deposits practically side by side and construction of very large (45 megawatt) furnaces, it is doubtful if anyone in the world can produce as cheaply.

LEACHING OPERATIONS

The statement is made in Glasscock's War of the Copper Kings that a miner named Ledford discovered the iron precipitation process previously unknown to the world's metallurgists. It's a nice story but untrue. Ledford did secure a year's lease on Anaconda mine water when it was still too low in volume to interest the mining companies.

In actual fact, this reaction was known to the medieval alchemists and was used commercially in Spain in the sixteenth century and Peru in the seventeenth. I assume this is about the time when iron became substantially cheaper than copper.

Up to 1889, the mines were too dry to produce much water, and what was produced was of low copper content. In that year, the St. Lawrence Mine caught fire and attempts were made to extinguish it by filling the mine with water. There were already too many crosscuts to other mines. The resulting pumping operations showed the water to be high in copper. At about the same time, enough workings had been opened in other mines to permit oxidation, and both water volume and copper content increased to the point where treatment was profitable. All the mining operations which had to pump very shortly installed precipitation plants.

As early as 1900, small lessors obtained rights to mine dumps, flattened the tops, made ponds, and percolated through the dumps. Somewhat later after the consolidation under Anaconda, plants were erected along Silver Bow Creek all the way from Meaderville to Harrison Avenue to leach ponded tailings from the early concentrators. These facilities were operated successfully until the depression prices of the thirties shut them down.

Also with the Anaconda consolidation, all pumping was centralized in the High Ore and Leonard mines. The High Ore and Leonard treatment plants were built about 1912 and treated all the water until after World War II. Flows stabilized at about 5,500 gpm. These plants were a combination of towers for heavy in-house scrap and launders using cheap scrap rail from the intercontinental railroads.

Efforts were made all during the period from about 1910 to 1950 to improve the copper grade of the pumped water by diverting flows underground to pass through filled old stopes to a lower level and introduce water from the surface through diamond drill holes to old workings and fire zones. Firm records as to the performance of these efforts are not available, but at least moderate success must be assumed since they persisted for such a long time.

When the pit fills and water treatment becomes necessary, such methods may prove feasible to enrich the waters by leaching areas above the level of the pit. Since much of the copper central zone has already been mined, this may be more important as a means of zinc enrichment. In this connection, a fire in the upper levels of the Buffalo Mine in the twenties was fought using water from surface diamond drill holes. The water from this zone, though in small quantity, had the astonishing assay of 40 gpl Zn. This is not folklore. When the Badger and Black Rock mine area was being filled in the late forties prior to zinc block caving, it was thought that large increases in zinc content might occur and make zinc recovery possible. This did not happen in these zones, but the diamond drill holes in the Buffalo were reactivated and the high zinc content of the solutions confirmed.

In the late forties, because of surface disruptions anticipated from block caving and because the rail plants were labor-intensive, the present Leonard precipitation plant was built as a tin can - launder plant of 6,000 gpm capacity. It was later expanded in two stages to about 20,000 gpm to accommodate the leaching operations resulting from the development of the Berkeley open pit.

Stripping operations and later mining in the Berkeley Pit resulted in the production of about 150,000 tpd of rock below treatment cutoff grade. This overburden was dumped in massive heaps between the Leonard precipitation plant and the tailings, and operations continued until the cessation of underground pumping.

The dumps were never as productive as hoped for because the Butte country rock broke down rapidly under acid attack, resulting in plugging and channelling. This necessitated the expensive method of solution introduction through drill holes of various depths rather than conventional sprinkling or ponding.

Nevertheless, the dumps were profitable, more so than generally realized or reported in the Profit and Loss statements. The Anaconda smelter produced more sulfuric acid than could be used locally after fertilizer manufacture ceased at the smelter. Production of acid could not be reduced for environmental reasons. Excess acid was disposed of wherever possible, mostly in Alberta, at give-away prices. The accountants, using typical "bean counter" reasoning, subtracted outside sales revenue from the total cost of acid production and charged the dump operation with the balance, resulting in exorbitant acid costs. A fairer system would have been to charge the dumps the same cost as could be realized in outside sales. The difference should have been charged to smelter pollution control.

The question is often asked why the Butte operation relied to the end on iron precipitation. It was not for lack of trying other methods. Those which come to mind are listed below:

1. Solvent extraction (more properly liquid ion exchange) followed by electrolysis is the present accepted method. The principal variable operating cost in LIX is loss of reagent which is proportional to the volume of water handled; on a cents-per-pound of copper, it is inversely proportional to the grade of copper in the water. The low grade of Butte water and the much higher capital costs made this uneconomical.

2. Solid ion exchange using synthetic resins had the same objections as 1. above. Both of these methods were tested on a pilot as well as a laboratory scale.

3. Membrane processes were tested only cursorily on a laboratory scale. Plugging of the membranes due to the precipitation of gypsum and iron salts discouraged further work. However, this was nearly twenty years ago and there have been many advances in membrane technology since then.

4. Hydrogen sulfide precipitation for both copper and zinc was highly attractive from a reagent cost standpoint and had the additional advantage of regenerating acid. The drawback was that the resulting precipitates were more like gels than granular particles. They thickened only to 2 percent solids and produced a filter cake with 90 percent moisture. Concerns about drying costs or, in other treatment methods than smelting, achievement of water balances caused abandonment of this work -- some thought prematurely.

5. Precipitation with lime with closely controlled pH to make a series of selective elements failed for lack of selectivity, again the gel-like nature of the products, and high lime costs.

6. Mass precipitation with lime of all major metallic elements other than alkalis produced a precipitate with relatively good settling and filtering characteristics. It was planned to then recover the copper and zinc by ammonia leaching. This was rejected because of the high lime cost.

The work on both processes 5. and 6. was done before large-scale leaching started, and at a time when the precipitation plant effluent was wasted down Silver Bow Creek without treatment. If lime costs in the case of scheme 6. had been charged to pollution control, the results might have been far different.

It should be emphasized that none of the work listed above had high priority. Top management did not discourage it, but always had higher priorities for more important projects.

Other possible future leaching projects merit discussion. In the period from 1910 to 1918, the Butte and Duluth Copper Company did pioneer work on leaching of oxide ores followed by direct electrolysis and achieved commercial success on a small scale (500 to 1,000 tpd). These ores occurred east of the Continental Fault in such small open pit mines as the Bullwhacker to the north of the present MRC operations. I have no idea how much oxide remains or what its grade is. If MRC operations eventually move this far, a successful overburden leaching operation may result.

Another possibility is the existence of the shallow manganese-silver deposits on the periphery of the district. Some 20 million tons carrying more than 1 oz/ton of silver have been located. The metallurgy has been worked out, but the silver price must be much higher to make these deposits economic -- something on the order of $15/oz. of silver.

The final possibility is so remote it is fairly safe to say it is beyond the lifetime of anyone here. It involves the very deep chalcopyrite deposits. In the early seventies, Anaconda mining and metallurgical research departments and the AEC Livermore Laboratories made a collective study. Livermore worked out a process using only water, oxygen, and high pressure, successfully leaching rubbleized rock. Conceptual studies showed that the required pressure could be maintained by preserving an 800-foot water column above the leaching operation. Use of deep shafts exterior to the leaching area could be successfully sealed from the water column and provide means of oxygen reduction and solution recovery.

The problem was how to rubbleize the rock. An atomic explosion was considered only about as long as it took to talk to the AEC underground test experts. A bomb at that depth, because of the shallow cone shock dispersal effect, could cause structural damage within a radius of 60 miles.

The possibility of using block-caving mining methods to remove about 20 percent of the bottom of the ore body and then cave the rest with conventional explosive was explored. Cost for this in 1973 was estimated at about $1.35 per pound of copper for this 20 percent of the reserve. With this number, the project was shelved for future generations.

SULFUR AND SULFURIC ACID

In Butte, as in most sulfide mining districts, the predominant sulfide is iron pyrite (FeS_2). Pyrite has been an important source of sulfuric acid since the inception of the chemical industry.

However, to be marketable, the pyrite must meet certain specifications. Unless sulfuric acid can be marked locally or with a freight advantage over competitors, the pyrite must have a value in the roasted revenue as well as for sulfur. These conditions can be met if:

1. The calcine contains less than 0.3 percent Cu and Zn. In this case it can be used for iron and steel manufacture in many parts of the world.

2. The calcine must contain 1½ to 2½ percent Cu, depending on copper prices. In this case copper can be economically leached out and marketed. The resulting residue may or may not meet iron and steel industry specs.

3. The pyrite must contain a desirable impurity such as molybdenum as in the case of Amax's mines in Colorado. MRC should note.

4. The pyrite must contain enough precious metal values to justify treatment in a copper or lead smelter. Generally a lead smelter will give better terms, both because the iron may be desirable and because silver recovery will be higher.

A special Butte case must be mentioned here. In the forties and fifties there were three lead smelters in the Salt Lake valley and they were short of value-bearing iron flux. It was found that pyrite from the Anaconda zinc concentrator tailings contained several times as much silver as copper tailings. This was recovered with an average grade of about 3 to 4 oz. Ag, and profitably sold to the Toole Smelter. The Asarco Smelter at East Helena was considerably closer, of course, but they received all the iron they wanted from the zinc plant residues from Anaconda and Great Falls. If zinc mining resumes in Butte, this should be reviewed. East Helena may have more need for an iron flux.

The first sulfuric acid plants were built in Anaconda to supply the phosphate fertilizer plant and leaching operations on tailings. They were of the chamber type and operated at first on copper concentrate. Because of enargite in the copper concentrates, this acid contained some arsenic. Some of the fertilizer produced eventually found its way as an additive to salt blocks for livestock. When this was discovered, production was switched to pyrite and continued until environmental constraints forced the construction of modern contact plants to treat gases from the zinc and copper roasters.

Anaconda pioneered the western phosphate industry and was the principal western producer for many years of both treble-super phosphate and phosphoric acid. The phosphate rock came from Conda, Idaho, and contained small quantities of vanadium and uranium. Vanadium became a byproduct, and uranium also would have been in the early fifties, were it not for the large uranium discoveries in the Southwest at that time.

The same geographical location which inhibited acid sales eventually killed the Anaconda phosphate plants. Phosphate production at Trail, B.C. always had a freight advantage in the Pacific Northwest. The growth of both wet and electric furnace plants in the Pocatello market shut off the Southwest. Everyone's costs were about the same, and freight became the determining factor.

From the above, it can be seen that while past sulfur production in the form of acid was impressive over a period of sixty years, future possibilities in this field are rather bleak. Geography predominates, and only a local market could justify production. Future leaching operations might justify a small plant.

APPENDIX A

MINERAL SPECIES IN BUTTE

Only the important ore minerals for each zone are listed. As mentioned earlier, the zoning effect is gradual and minerals persist, but in decreasing quantities from one zone to the other.

1. Central Zone

Chalcocite	Cu_2S
Enargite	Cu_3AsS_4
Bornite	Cu_3FeS_4
Chalcopyrite	$CuFeS_2$
Covellite	CuS
Tetrahedrite	$(CuFeZnAg)_{12}\ Sb_4S_{13}$
Tennantite	$(CuFeZnAg)_{12}\ As_4S_{13}$

The minerals are listed in decreasing order of importance. Enargite is a relatively rare mineral in all but a few copper mines but is very important in Butte, both as a source of copper and as the source of major difficulties in metallurgy and in waste disposal.

Tennantite and Tetrahedrite are of little importance as a copper source, but are major contributors of silver.

It might be well to mention here that gold is contained in about equal amounts in all three zones, and because of the tremendous tonnage treated over 100 years, the production has been substantial. In terms of dollar values, however, silver has been far more important. Platinum-group metals are also present in very small quantities and are eventually recovered.

2. Intermediate Zone

Sphalerite	ZnS
Galena	PbS
Greenockite	CdS

Greenockite is so intimately associated with sphalerite so as not to be recognizable to the eye. The sphalerite composition listed is for the pure mineral. The Butte variety, however, contains some iron and is the variety known as "Black Jack" or marmatitic sphalerite.

The sphalerite also contains germanium, indium, and gallium in quantities not detectable in the ore, but which are finally concentrated in zinc plant flue dusts in recoverable quantities.

3. Peripheral Zone

Pyrolusite	MnO_2
Rhodochrosite	$MnCo_3$
Rhodonite	$MnSiO_3$

Other manganese oxides known collectively as "Wad"

Of the manganese minerals, only rhodochrosite has been an ore of manganese. The others are important only as carriers of silver, some of the mechanisms of which are still not clearly understood.

ECONOMICS OF METALS POTENTIALLY RECOVERABLE FROM THE BERKELEY PIT

By

John C. Brower

Montana College of Mineral Resources and Technology

Dr. John Brower, a member of the faculty at Montana College of Mineral Sciences and Technology, is widely traveled throughout the mineral-producing regions of the world. He is considered extremely knowledgeable about relative values of mineral resources.

INTRODUCTION

This paper was prepared for presentation at the Headwaters Research Institute conference, January 20, 21, and 22, 1987, dealing with the problems and potential for cleanup of water accumulated in the abandoned Berkeley Pit copper mine. Its purpose is to try to give some perspective to the value and marketability of some of the 23 metals found by chemical analyses to be present in the pit's water (see Sonderegger, 1986).

Of these metals, seven with the highest concentrations were selected: aluminum (Al), copper (Cu), Magnesium (Mg), Manganese (Mn), Zinc (Zn), and silver (Ag). Although iron and calcium also occur in high concentrations, they were not considered for review due to their very low value. Other metals and compounds also occur in the water, although at much lower concentrations than the seven selected, thus making their recovery more difficult and more expensive. In any case, most, if not all, of the metals found in the Berkeley Pit water would follow the economic patterns of demand and prices described in the seven selected.

STATE OF THE METALS MARKET

Worldwide, metals have taken a beating on both prices and demand. The broad trend for metals taken as a group is gradually downward. This is a reflection of several important factors. First, mining companies have had considerable success in finding large, low-grade ore bodies containing huge amounts of minerals, and in creating the technology to mine the ore and extract the contained metals at low cost. Clearly, in terms of natural resources, there is no physical shortage of metals, nor is there likely to be in the foreseeable future. That being the case, competition between large-scale, efficient producers is likely to keep downward pressure on metal prices. Moreover, if it is true that producers are willing to supply the same amount of metals at lower prices than before or even more metal than before at the same or lower prices, then this implies that the supply curve for metals has shifted and metals are in greater supply than before. This is, of course, not likely to result in higher prices for metals in the future.

Second, on the demand side, the high growth rates for metals experienced in the two decades after World War II have started to slow. In some cases, not only is there a relative decline in the rate of growth, there is also an absolute decline in the tonnages of metal consumed. The reasons underlying this are: 1) declining intensity of use of metals in the economy; 2) recent economic recession; and 3) substitution.

Intensity of use refers to the physical amount of energy or materials used in generating a unit of gross national product (GNP). Thus a relationship exists between pounds of metal consumed per dollar of GNP generated. It is generally held that poor countries that use human and animal labor and place few demands on the economy for machinery, buildings, etc. have much lower intensities of use than do the advanced, industrialized nations in terms of materials and energy. In plotting the data relating intensity of use and GNP, it can be seen that the curve rises rapidly at first, gradually levels off, and may even decline at high levels of GNP. Increasing intensity of use occurs as basic infrastructure (roads, dams, power plants, factories, etc.) get built up and the growing needs for capital and consumer goods are met. Once these needs are satisfied, growth in use of materials will slow, being linked mainly to replacing obsolete equipment and facilities.

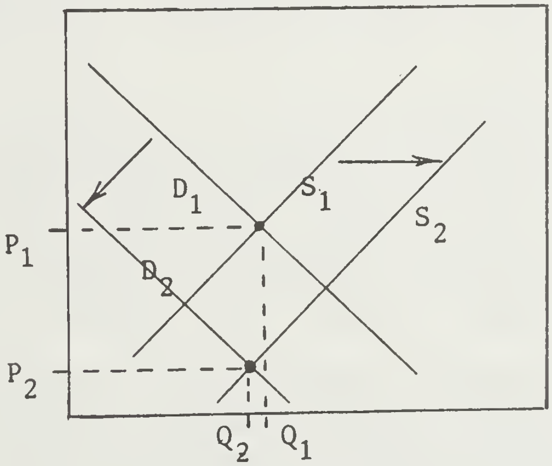
Most people are aware that the economy of the United States is shifting away from heavy industry towards service sector businesses and employment. Making computer software on diskettes requires far less metal than making tractors for export. As yet another example of lower intensity of use associated with higher standards of living, consumers now drive more cars, but the cars contain significantly less metal; thus economic "well being" has increased, but intensity of use of metals and gasoline has decreased. The overall result is that less metal is needed in order to generate today's high GNP, compared to the economy of the United States a couple of decades ago.

The recent economic recession of 1980-82 was costly to the metals industry due to lower demand and lower prices. The data and diagrams in this paper reveal declining trends for demand and prices associated with the recession, which tend to depress the longer-term growth trends that extend back into the 1950s and 60s.

Substitutes for metals are becoming more and more common. Plastics and composites are now common in automobiles and aircraft, both for weight-saving (linked to fuel efficiency) and technological reasons (high heat, severe forces). Indeed, research is underway to build ceramic and plastic automobile engines, the principal remaining use of cast iron in cars. Fiberglass panels and complex shapes substitute for sheet steel and aluminum processings. Plastics substitute for zinc in automotive castings, and fiber optics are replacing copper wire in communications.

SUPPLY AND DEMAND EQUILIBRIUM

The amount of metal that producers are willing to supply and that consumers are willing to buy at various prices is represented by the familiar supply and demand curves shown in the following diagram. The levels of supply and demand of a couple of decades ago can be generalized by supply curve S_1 and demand curve D_1, which intersect at the equilibrium market clearing price P_1, and quantity purchased, Q_1. The apparent increase in the world's supply of metal would shift the supply curve to the right, to the new position S_2. This shift alone would result in the lowering of metal prices in order for the market to reach a new equilibrium.



Prices could only be maintained at the existing level if the demand curve also shifted to the right (increased). But real prices are lower, implying that the demand curve stayed put while the supply curve has shifted, or even that the demand curve, too, may have shifted to a lower position, D_2, resulting in less metal being consumed and at lower prices, P_2. Whatever the reasons, it appears that fundamental changes have taken place in the metals market, resulting in low prices and lower demand.

PRICE AND DEMAND FORECASTS

Forecasts, by necessity, have to be based on the past. The near future, if based on the recent past, is easier to forecast than the distant future. Long-range forecasts are reliable only if the pattern being forecast has been unchanged for very long periods of time. Economic forecasts suffer from the fact that society and the economy are constantly changing, both on a national and world scale. Patterns of past decades might not be reliably forecast into the future. Technological breakthrough cannot be predicted, and yet has profound effects on the usage of energy and materials. Likewise, political upheaval cannot be forecast, yet can have profound effects. Witness the Arab oil embargo of 1973 and the upheaval in Iran in 1979. In the accompanying table and figures, the demand forecasts were prepared by the U.S. Department of the Interior, based on time series data from 1963 to 1983, and using regression analysis techniques. From the perspective of this long-term series, the projections for 1990 and the year 2000 seem reasonable, but based on the more recent years, they seem in most cases to be far too optimistic.

However, two factors should be mentioned. First, in order to keep the demand diagrams in this paper simple and uncluttered, only the "probable" estimate is shown, and the "high" and "low" estimates made by the Department of the Interior are omitted. Had they been shown, the great degrees of uncertainty surrounding the forecasts would be apparent.

Second, tastes and technology have changed since the 1960s and 1970; and therefore to project their demand patterns into the future is to invite error. But from a practical standpoint, there is little else that forecasters can do but to work with existing data and attempt to alert readers to uncertainties. The danger is always that the warnings will be ignored, and rough forecasts will be taken as reliable certainties.

Long-range price forecasts are difficult to obtain, and are notoriously unreliable. Nonetheless, expert opinion about future prices is an indication of expectations about an important element in market clearing conditions. Expert opinion that real (i.e., inflation-adjusted or constant) prices will rise indicates that they anticipate increased demand or tighter supplies, or both. The opposite, of course, applies to expectations of lower prices.

The World Bank conducted a survey in mid-1986 of experts in the minerals industry, asking their predictions of prices in 1986, 1987, 1988, 1989, 1990, and 1995. The "most probable" price forecasts, in constant 1986 dollars, are plotted on the accompanying metal price diagrams. Again, readers are warned that the ranges of uncertainty surrounding the forecasts are not shown, and in most cases they are considerable. Forecasts included aluminum, copper, and zinc, but none of the other seven metals selected for this paper. In general, the forecasts show gradually rising prices for aluminum, copper, and zinc, but even in 1995 reaching levels far below their earlier highs of the 1970s. The reasons for forecasting particular prices were not requested of the experts, so one can only guess at why higher prices in the short term were forecast. It is significant to note that the longer term forecasts are not particularly optimistic, and even at that are more optimistic than this writer believes.

In summary, there seems to be no reason to expect a turnaround in demand for metals, or a constraint on their supply. This will likely result in no significant increase in the real price of metals.

SPECIFIC METALS

Aluminum

The U.S. is a major consumer and importer of aluminum in the form of bauxite (aluminum ore), the intermediate product, alumina (aluminum oxide), and aluminum metal in the form of ingots and rolled sheets and shapes. The aluminum plant at Columbia Falls, Montana, processes imported alumina into aluminum metal on a fee basis for the alumina owners. Conversion of alumina into aluminum requires huge amounts of electricity. The concentration of aluminum smelters in the Pacific Northwest is due to heretofore inexpensive hydroelectricity from the Bonneville Power Administration. With increased power costs from the BPA and other sources, many U.S. aluminum plants are shut down and may never reopen. On the one hand, this may be beneficial by forcing high-cost producers out of the market, but on the other hand, it may be handing market power to foreign producers which may result in even higher prices in the future. It should be noted that attempts by some bauxite producers to form a cartel and increase prices have so far failed, due in part to worldwide excess capacity in the aluminum industry. Some Third World countries that have both bauxite and hydro power, such as Brazil, Surinam, and Guyana, have built aluminum smelters that now compete with U.S. producers.

The U.S. has very limited bauxite resources, the only commercial ones being in Arkansas. Research has shown that kaolin clay and the igneous rock anorthosite can be processed to yield aluminum, but so far the processes are uneconomical. It is therefore likely that the U.S. will continue to rely on imports.

The demand for aluminum is based mainly on its favorable combination of lightness and strength. Aluminum is being used increasingly to substitute for sheet steel and cast iron in automobiles, as automakers attempt to improve gasoline mileage through weight reduction. Use in these applications will probably continue to grow. These same properties are responsible for growing use of aluminum in construction and for beverage containers. It has almost completely replaced steel in beverage cans, many of which are recycled, and has completely replaced copper in long-distance high voltage electric transmission lines.

In summary, the demand for aluminum appears likely to increase gradually in the future, with concurrent upward adjustment in prices.

Copper

The U.S. is a major copper producer and could probably meet all of its domestic requirements from domestic resources, but at much higher prices than the current market will permit. Ore grades in the U.S. are

FIGURE 1

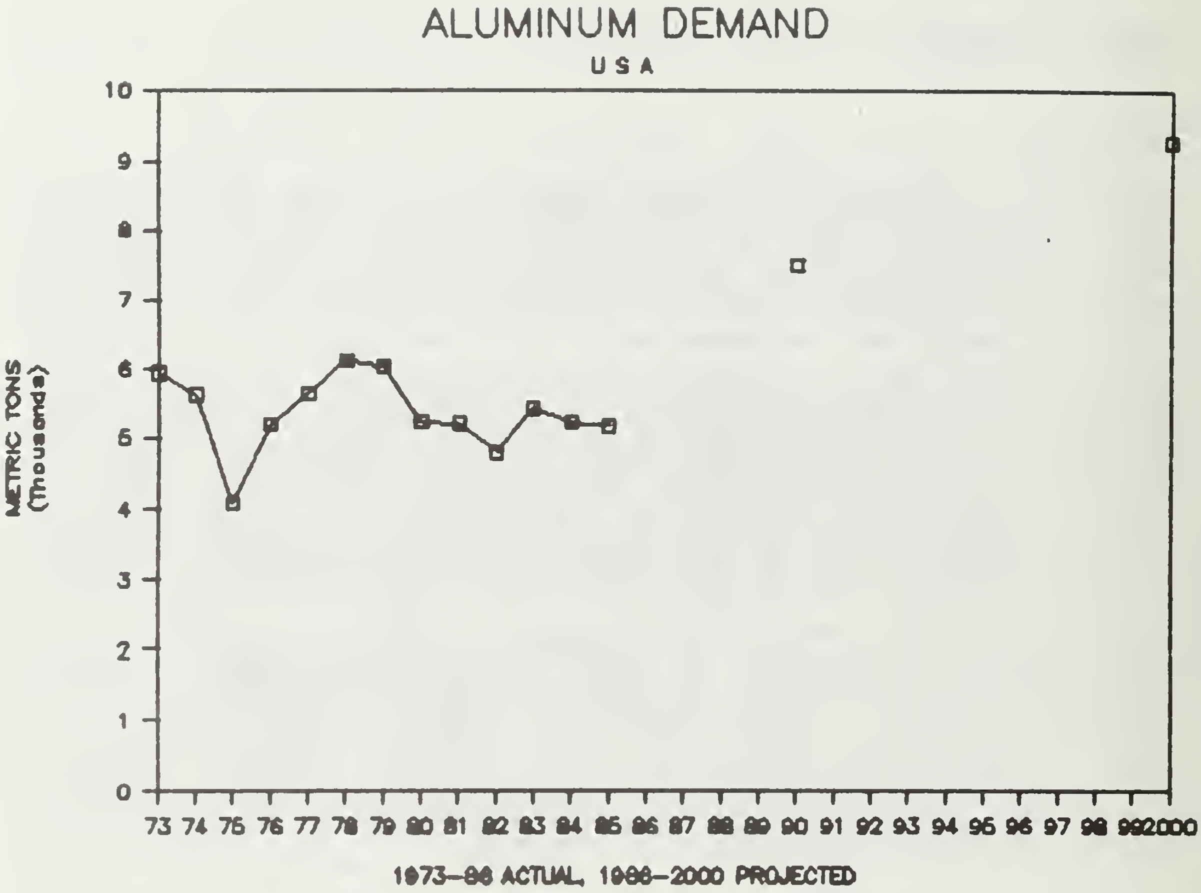
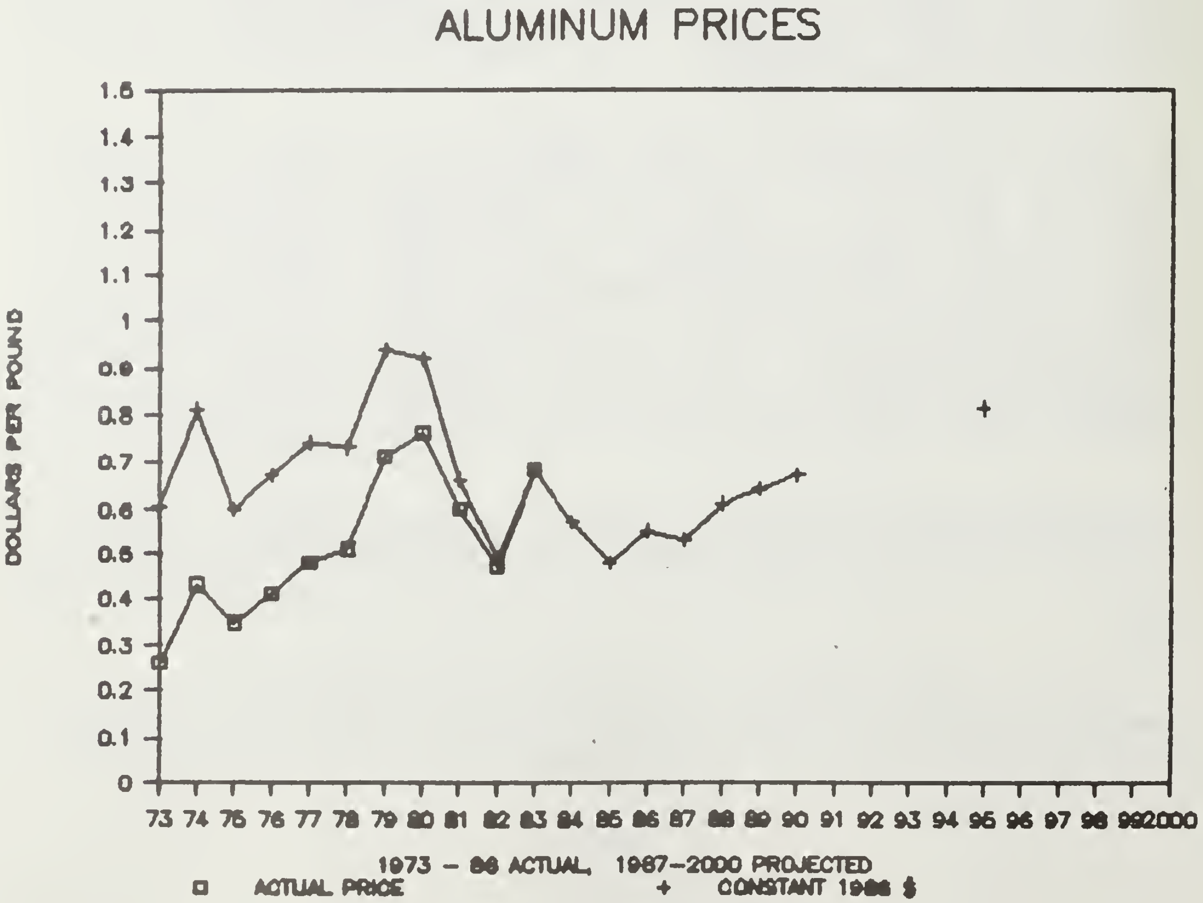


FIGURE 2



generally lower than those of the major foreign producers and labor costs are much higher. The result is that much of the U.S. copper mining capacity is shut down and the industry is going through the difficult period of either permanent plant closure or re-opening of plants with improved efficiency in labor and technology, usually after prolonged labor disputes, and capital investment. The Phelps Dodge copper company in Arizona, for example, can produce limited amounts of refinery-grade copper by the solvent extraction - electrowinning process in the range of $.25 to $.35/lb., completely bypassing the conventional system of ore grinding, concentrating, smelting, and refining. They are examining the possibility of expanding capacity using the new technology. Both Phelps Dodge and Montana Resources, Inc., have reopened conventional copper mines and mills with smaller and lower-paid work forces, and are making small profits with copper at $.60/lb., whereas earlier they lost money at $.90 or even above.

Given the large tonnages of copper contained in known ore bodies around the world awaiting initial development or expansion and the improved technological efficiency in the copper industry, there seems to be no reason to expect significantly higher prices for copper in the long run.

The demand for copper has stayed fairly even over the past decade, with losses to substitutes compensated by growth in the housing, commercial building, automobile, and electrical appliance industries, all of which use large amounts of small-gauge copper wire, still not threatened by aluminum wire. As mentioned earlier, fiber optics are quickly gaining ground over copper for telecommunications.

In summary, there are compensatory forces on both the supply and demand sides of the copper market that will probably serve to keep real copper prices near present levels into the foreseeable future.

Magnesium

Magnesium is an extremely abundant element in the crust of the earth, and in seawater. It is produced principally from seawater and from brine at the Great Salt Lake. It is also mined as the mineral magnesite ($MgCO_3$) and the rock dolomite ($CaMgCO_3$). Its greatest form of use is in chemical compounds and for inert, heat-resistant "refractory" brick used in lining smelters and furnaces. Only about 15 percent by weight is used as metal, and most of that is consumed as an alloying agent in aluminum.

While the use of metallic magnesium has declined slightly from its 1979 peak, its use primarily in refractory brick has fallen dramatically, reflecting mainly the decline of the U.S. steel industry and also the closure of base metal and aluminum smelters. The loss of a large percentage of this market is likely to be permanent.

FIGURE 3

COPPER DEMAND

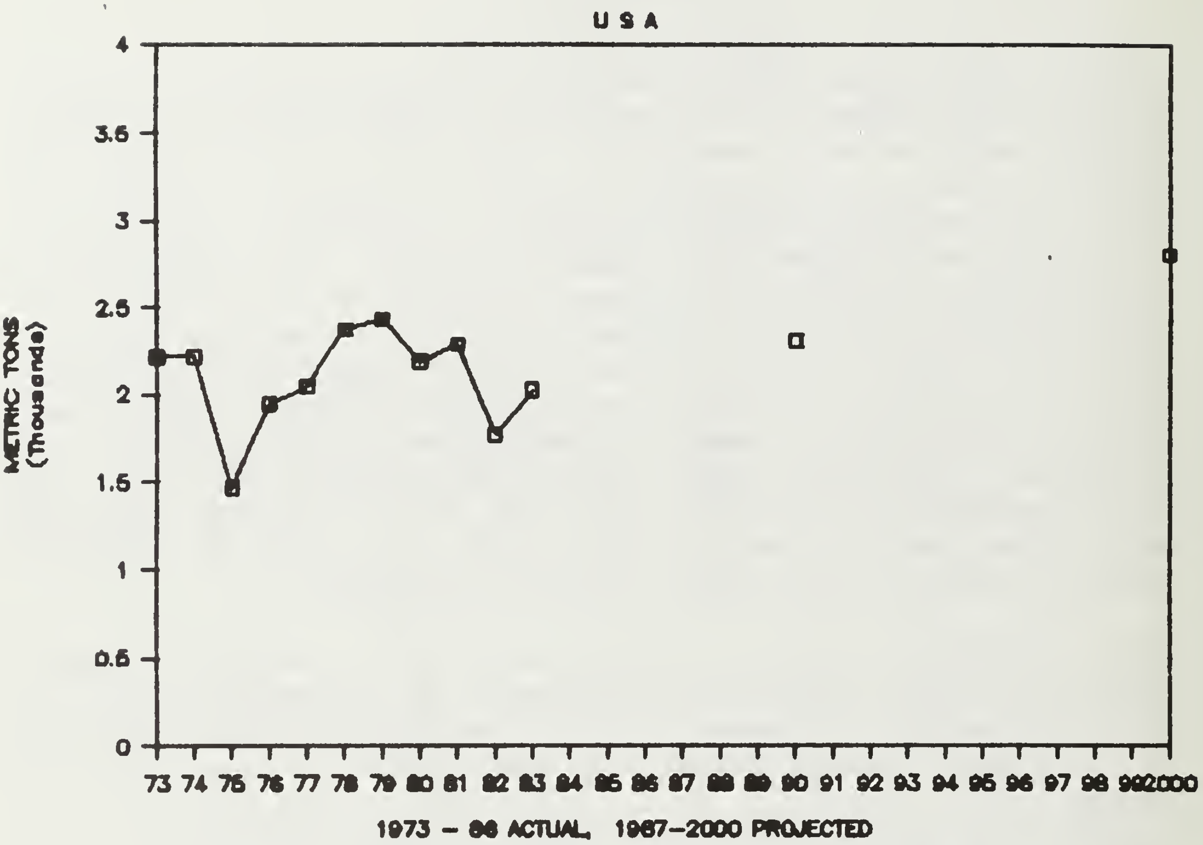
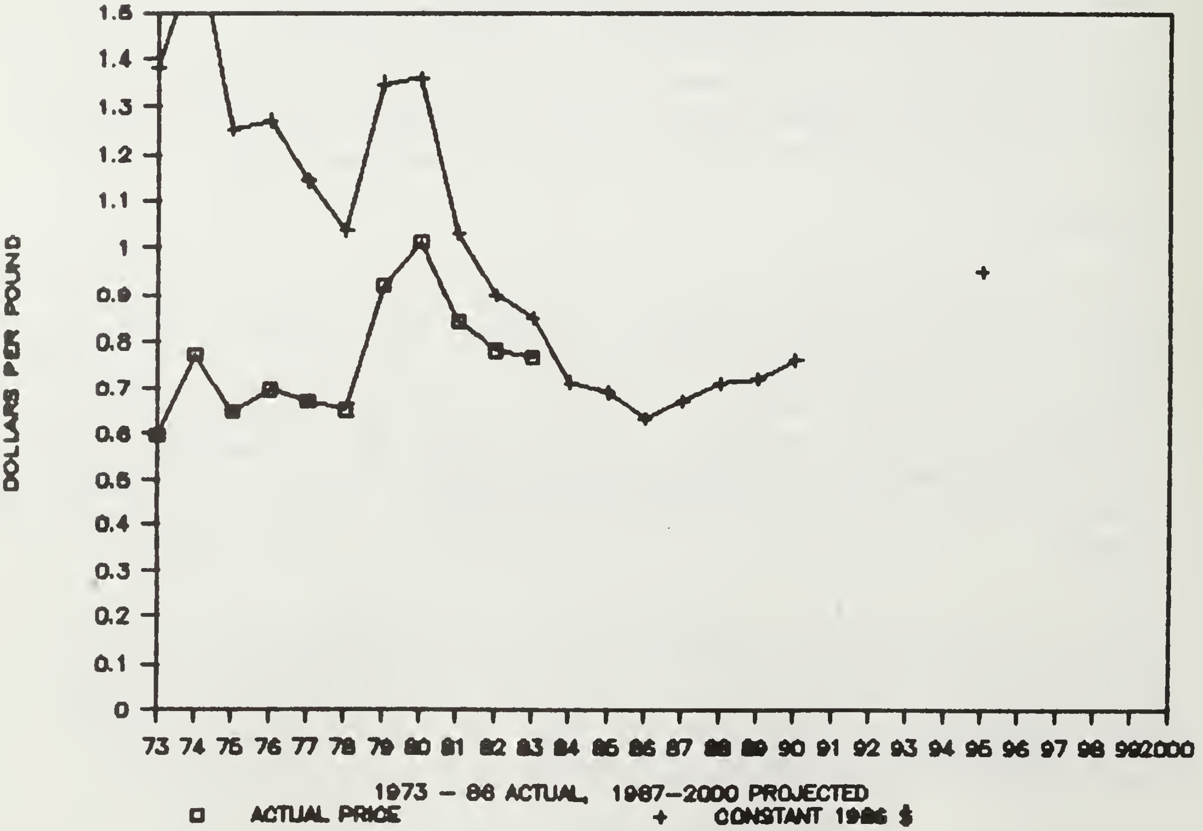


FIGURE 4

COPPER PRICES



Magnesium prices have increased in current dollars (actual yearly prices) and have remained remarkably stable in real (constant) dollars. The ability to increase prices in the face of declining demand is a reflection of the fact that the magnesium industry is dominated by three large firms: Dow, Amax, and Northwest Alloys, who can exercise market power to constrain supply and maintain prices.

In summary, given the loss of customers for refractory brick and the scenario of modest growth in aluminum demand as well as the closure of aluminum producers in the United States, the best that can be hoped for is stable demand at a lower level than before and stable prices at today's real level of about $1.50/lb. for metal and about $200/ton for non-metallic magnesium.

Manganese

Manganese ore, consisting mainly of large deposits of manganese oxide (plus varying amounts of iron oxide) is the chief source of manganese. Although manganese is a common element, the United States has no manganese mines at present, although there were some in the past, and is completely reliant on imports.

About 95 percent of manganese use is in iron and steel making, where it is essential as a de-oxidant and de-sulphurizer. In this application it is used in the form of ferromanganese, derived from smelting manganese ore. Metallic manganese is used as an alloy in steel, and to a lesser degree in aluminum and bronze. Manganese chemical compounds are used in water purification, soil conditioning, welding rod fluxes, and ceramic glazes. Battery-grade manganese is used for making dry cell batteries.

The drop in demand for manganese reflects the loss of its major market, the steel industry. Prices have fallen accordingly. There is no reason to expect that the present low level of demand and prices will change in the foreseeable future.

Molybdenum

Molybdenum occurs principally as the mineral molybdenite (MoS_2). Mining of molybdenite deposits furnishes about 70 percent of production, and the remainder is a byproduct of copper mining, as in the Butte district. The U.S. is the world's major producer, with much of the production coming from the Climax and Henderson mines in Colorado, owned by Amax.

Molybdenum is consumed mainly in the steel industry as a steel alloy, accounting for about 90 percent of its use. It is vital for toughening and hardening of steel. The state of the steel industry has been men-

FIGURE 5

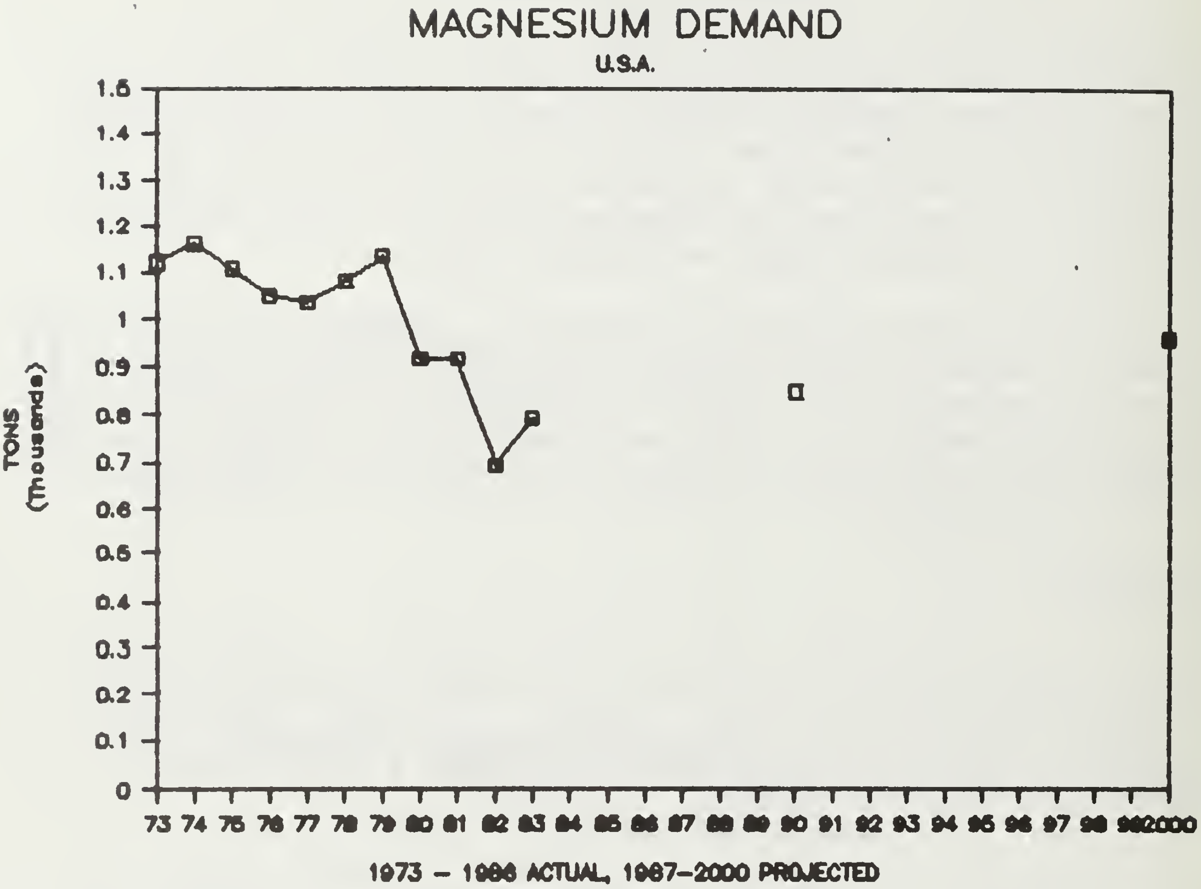


FIGURE 6

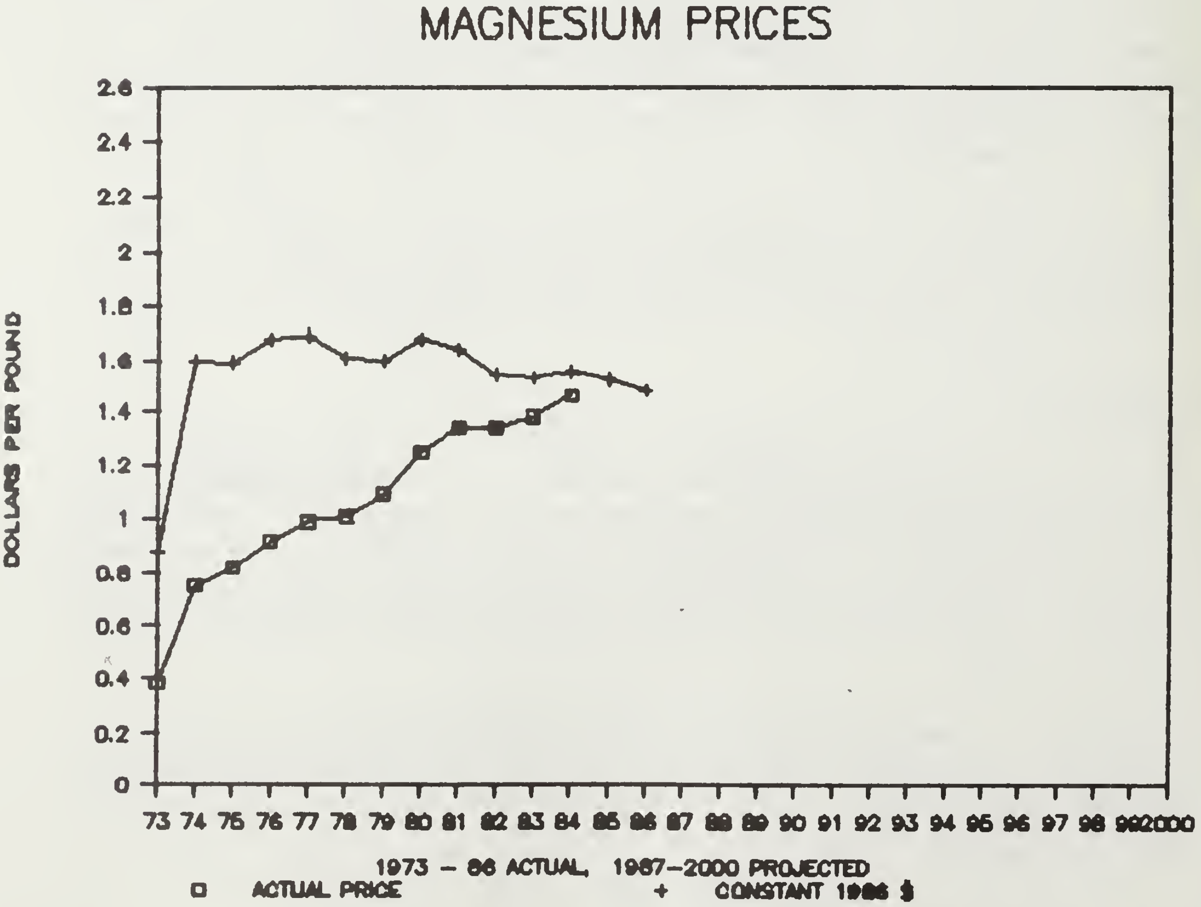
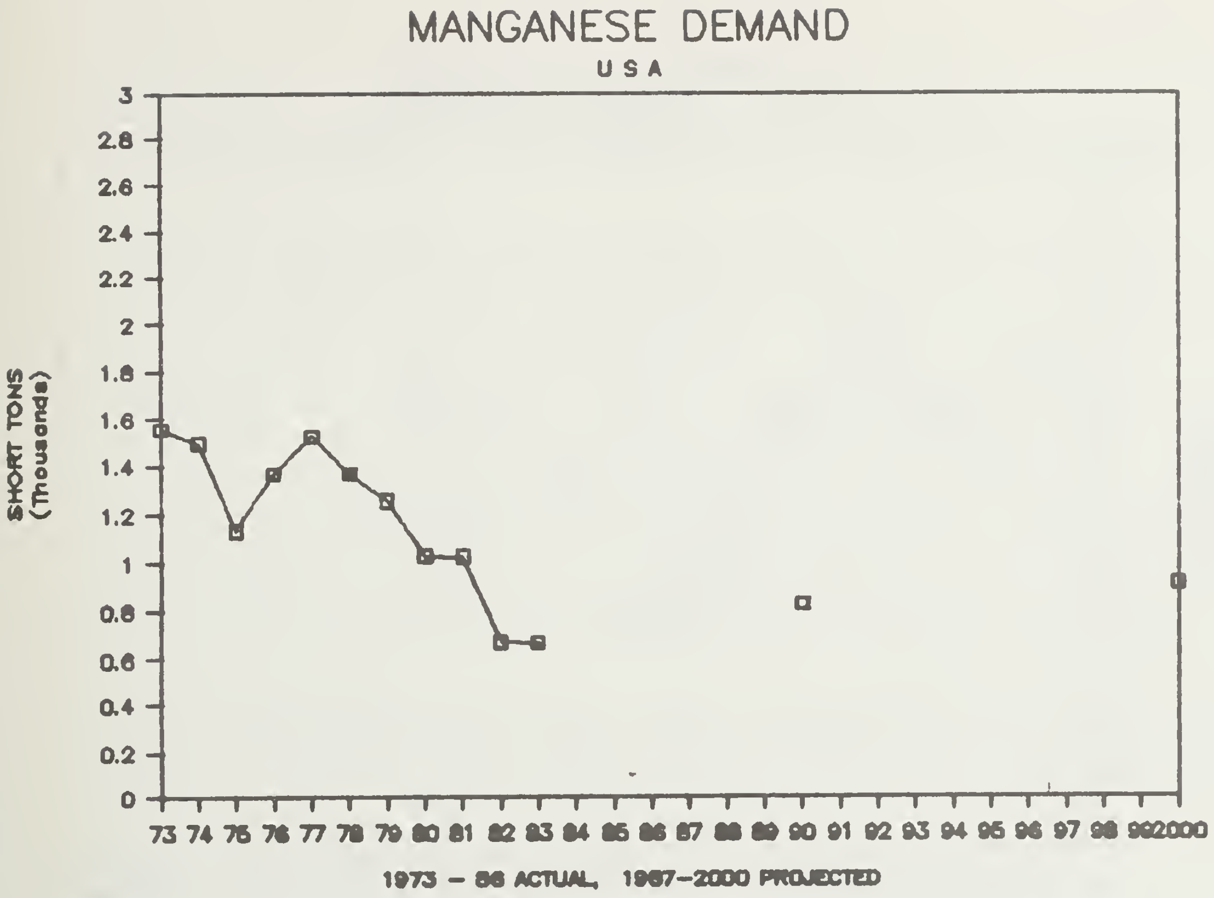


FIGURE 7


MANGANESE DEMAND

USA

FIGURE 8

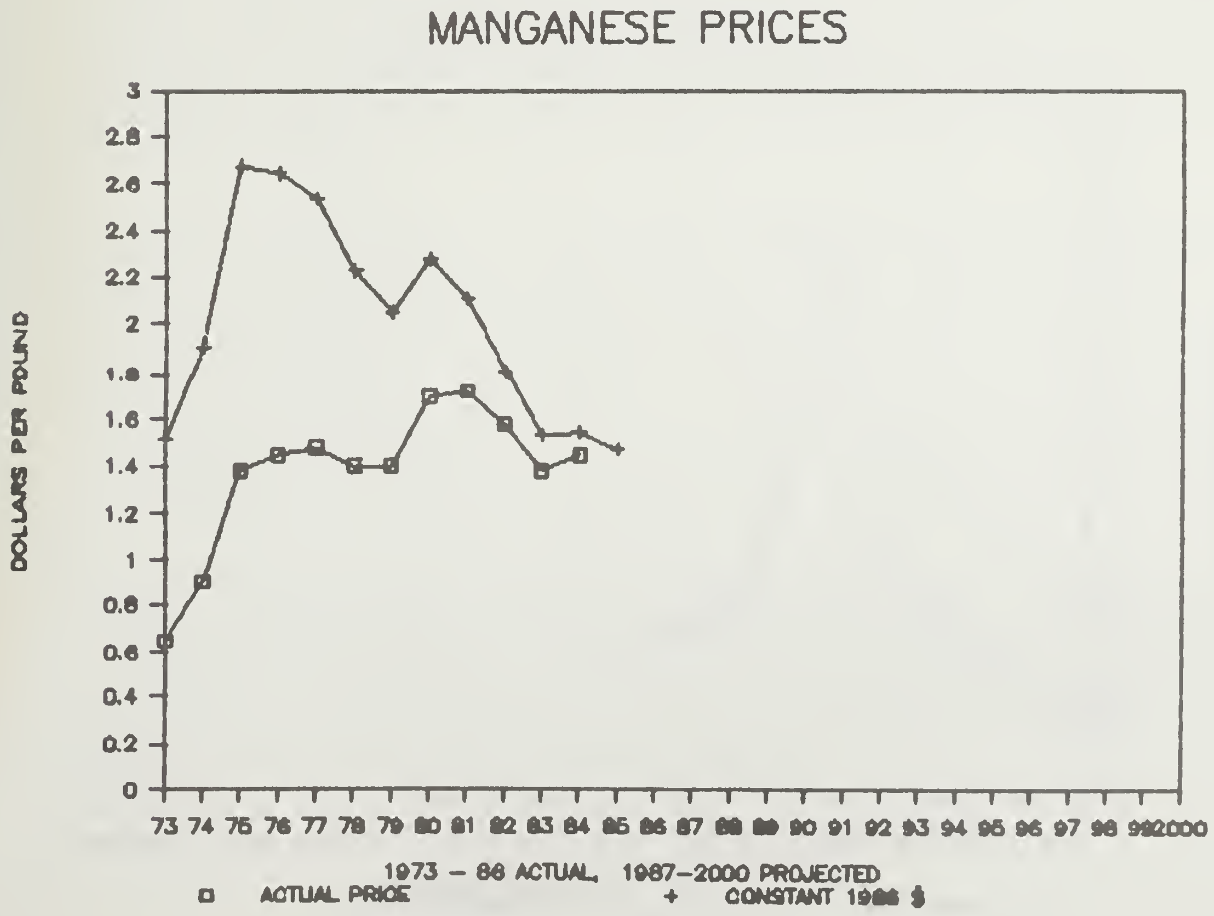

MANGANESE PRICES

FIGURE 9

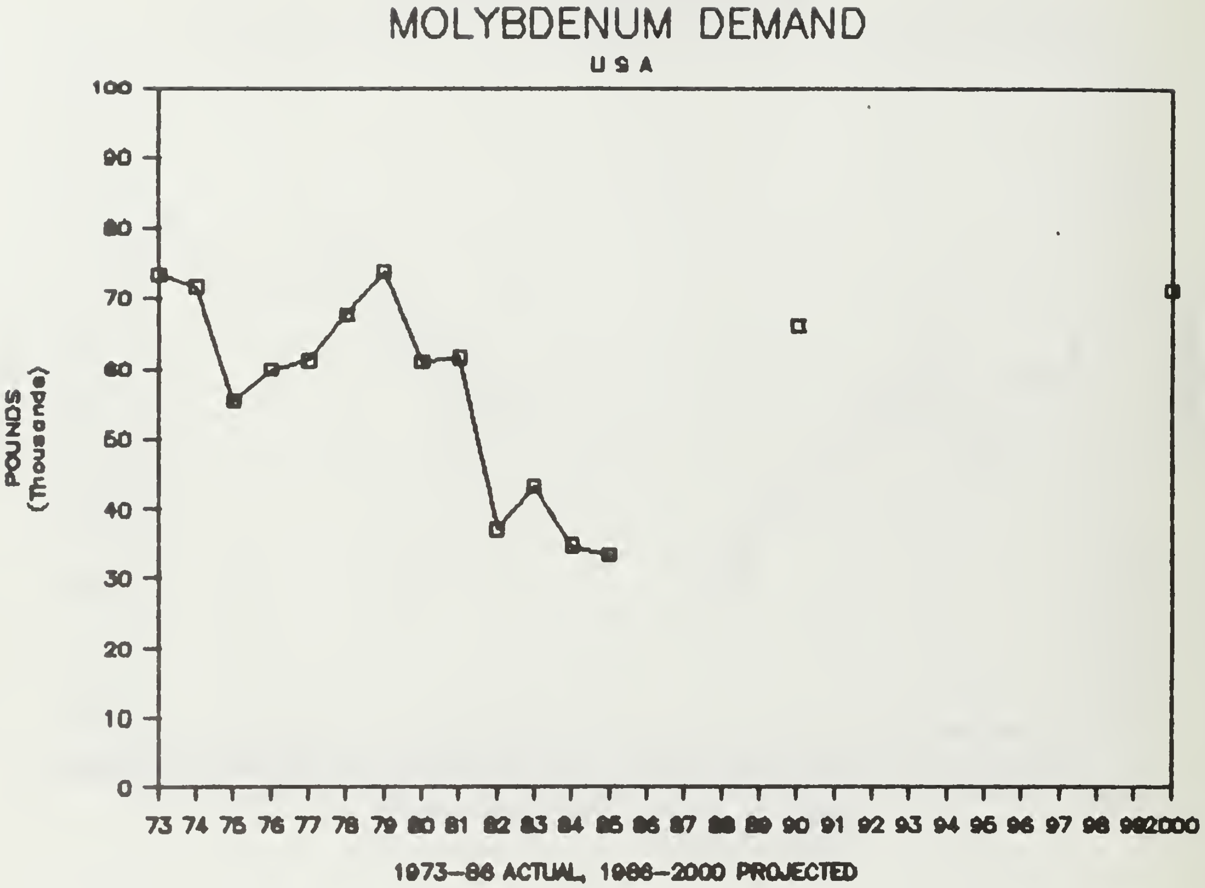
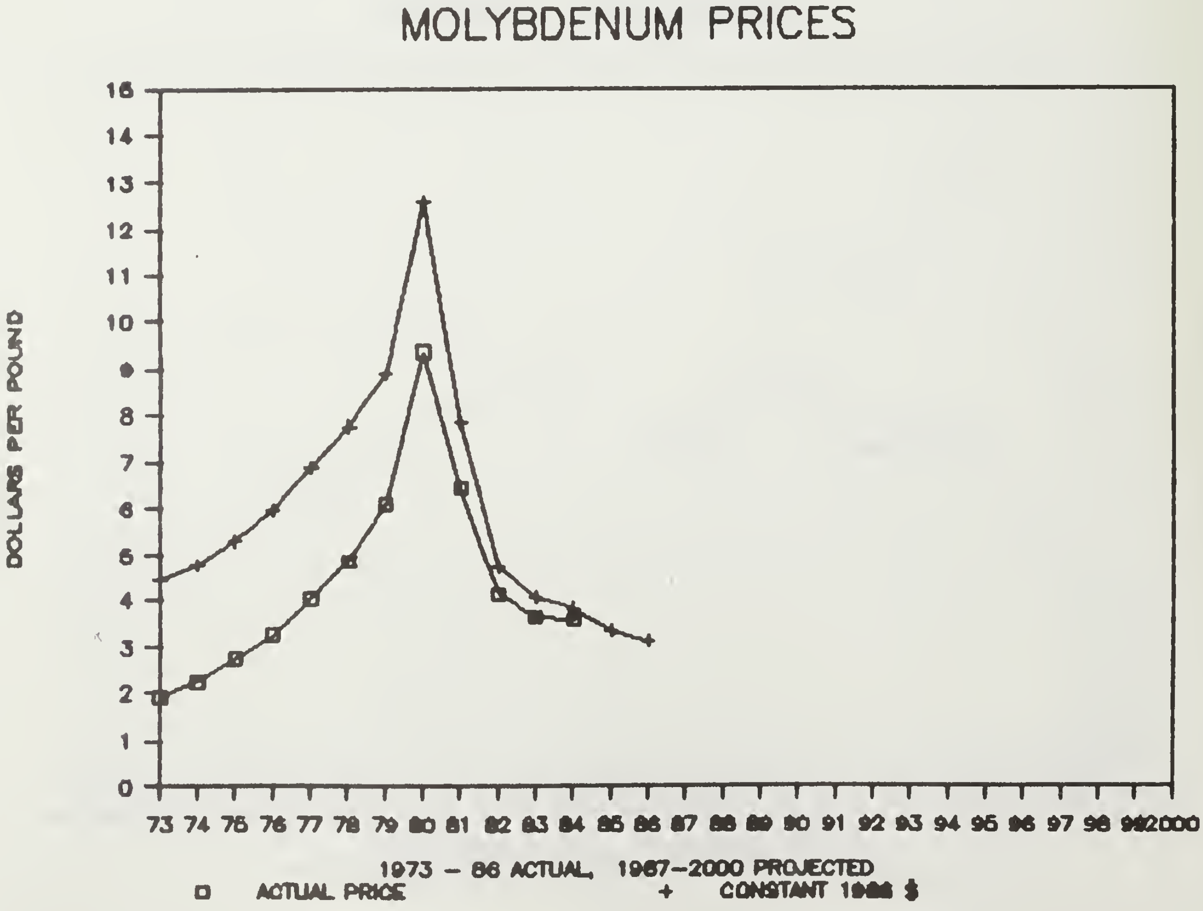


FIGURE 10



tioned above. Other uses are as a catalyst in chemical processes and petroleum refining, as a flame and smoke retardant, and as a lubricant.

Prices for molybdenum rose sharply in the late 1970s, reflecting an increase in demand and a tight supply situation. Part of the tightness was the depletion of the U.S. strategic stockpile in 1977, removing a real or potential source of competition. The high prices induced increased supply from foreign producers, causing subsequent surplus availability of molybdenum. Also, in 1980, tariffs on imports were reduced in accordance with the General Agreement on Tariffs and Trade (GATT) schedule. The combined effect was a plunge in prices. But in response to the sharply rising prices of the 70s, exploration for molybdenum was increased, resulting in major new discoveries being made in Idaho and Alaska. The Idaho discovery is now in production, and the one in Alaska has had development halted due to low prices.

With the steel industry down and major new competition in the market, it is unlikely that the former high molybdenum prices will be seen again, and the very high demand forecasts for 1990 and 2000 seem unrealistic.

Zinc

The principal sources of zinc are ore bodies of the mineral sphalerite (ZnS). Zinc also commonly occurs in the principal lead mineral galena (PbS) and is therefore a common byproduct of lead mining and also of mining large copper ore bodies. Although the U.S. is a major producer, it consumes in excess of production and therefore is a major importer, mainly from Canada although there are several other important sources as well.

The single largest use of zinc is for corrosion protection in galvanizing sheet and structural steel. It is also used as an alloy with copper to make brass, and as a minor alloy in other metals. Zinc die castings are used extensively in the automobile industry, but have suffered to competition from plastics in certain applications such as ornamental trim. This loss has been offset by the greater use of one- or two-sided galvanized body panels. This in turn has been hurt by the downsizing of U.S. cars, consequently using less sheet steel, and growing numbers of imports.

Zinc demand has stayed remarkably even, trending only slightly downward. Nominal prices have increased gradually since the 1970s, but real prices have declined. Since the demand for zinc is linked closely to the heavy construction and automobile industries, which appear to be maturing, and since world supplies are adequate, there seems to be no reason to assume increased prices or demand.

FIGURE 12

ZINC PRICES

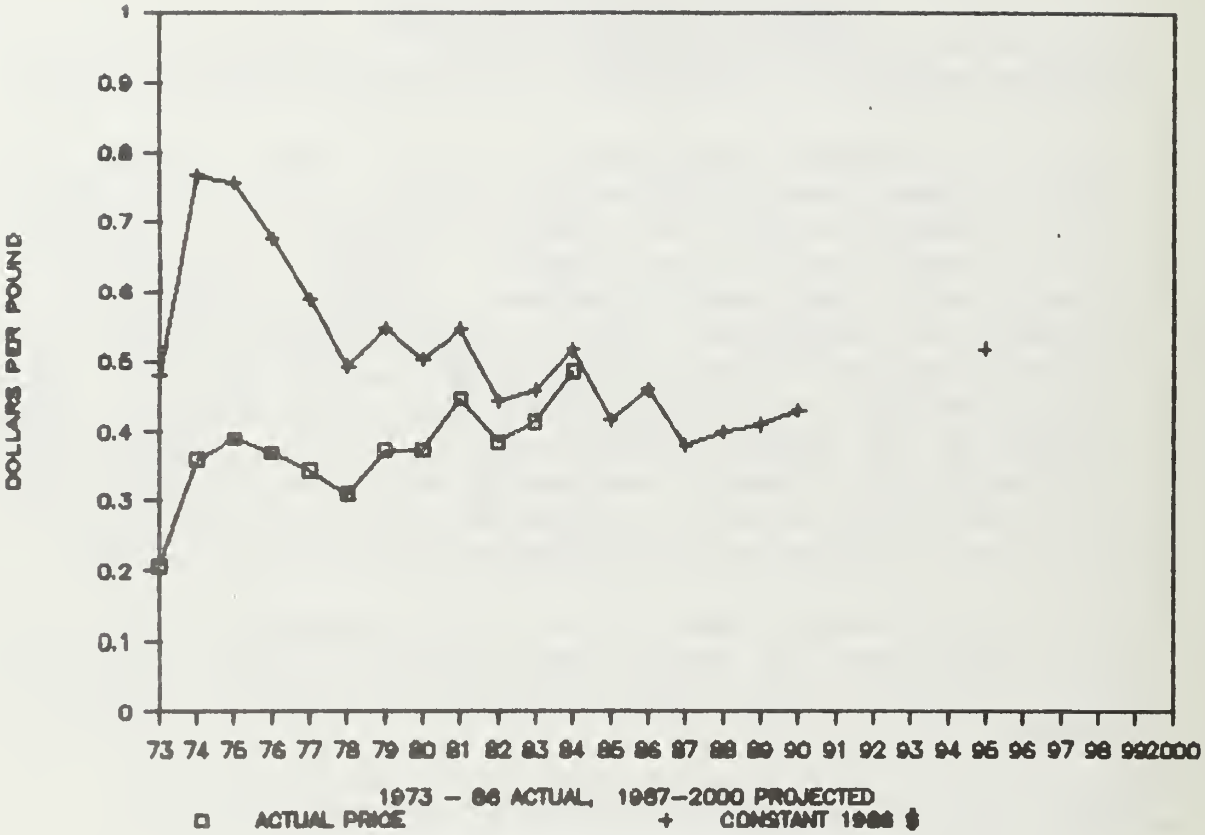
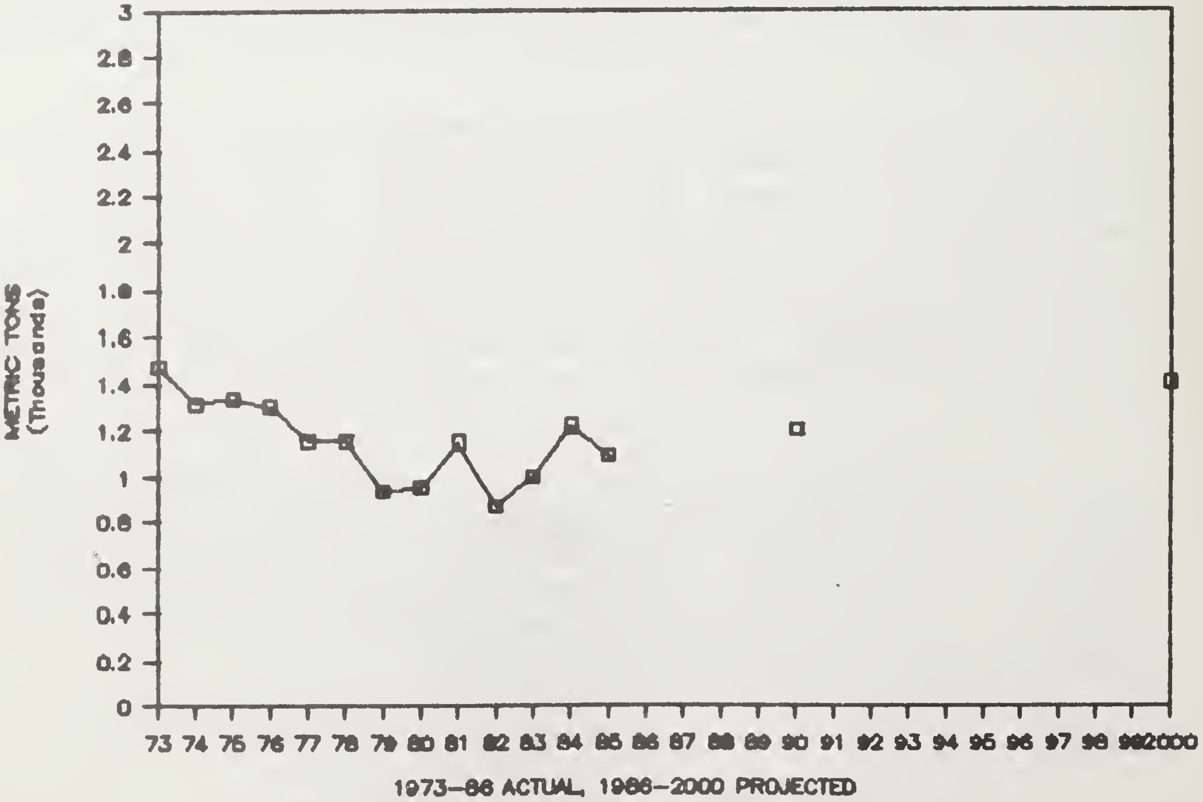


FIGURE 11

ZINC DEMAND

USA



Silver

Silver is obtained directly from hard rock silver mines, as in Idaho and the Troy mine near Libby, Montana, and also as a byproduct from lead, zinc, and copper mines. Small amounts are common in the copper ores of the Butte District. Although the demand for silver in the U.S. is greater than the amount of silver newly mined, no shortage has developed or is likely to, for three important reasons.

First, silver is mined and exported on a large scale from Canada, Mexico, and Peru, and there are many other smaller producers as well. Imports are therefore readily available at prices reflecting low production costs. Second, silver is recycled from scrap materials currently equalling about half of the level of newly mined silver and equally it in some years in the past. Third, the silver hoard in the U.S. and the rest of the world in the form of jewelry, silverware, ornaments, coins, and bullion bars is enormous. The high prices of 1978-80 brought forth an outpouring of hoarded silver.

In terms of newly mined silver, although the silver mines of the Coeur d'Alene District in Idaho are shut down due to low prices, two very large mines are likely to be developed in northwestern Montana, in the general area of the Troy mine. When they come onstream, the supply of newly mined silver will increase dramatically. Foreign producers, particularly Peru and Mexico, are likely to remain as major sources, since they need hard currency from silver sales to service their foreign debt payments. These factors combine to assure the ready availability of silver in both the short and long run.

On the demand side, the trend has been downward. The principal industrial use of silver is in photography, and the film manufacturing industry has been successful in reducing the amount of silver required in film. Research towards this end was accelerated by the high prices of 1979-80. Also, magnetic media and xerography have eroded the market for photosensitive film and paper. Videotapes have all but replaced home and special event movies, and even Eastman Kodak is marketing VCR "cam-corders" and cassettes.

The second largest use of silver, electrical contacts and conductors, has lost ground to gold and platinum/palladium due to the better resistance of these metals to oxidation, which is especially critical in devices such as computers, calculators, quartz watches, etc. that use very low voltages and currents.

In addition, silver has been eliminated from coins, which now have nickel cladding over a copper core, and it has been substituted by aluminum and rhodium for "silvering" mirrors.

FIGURE 13

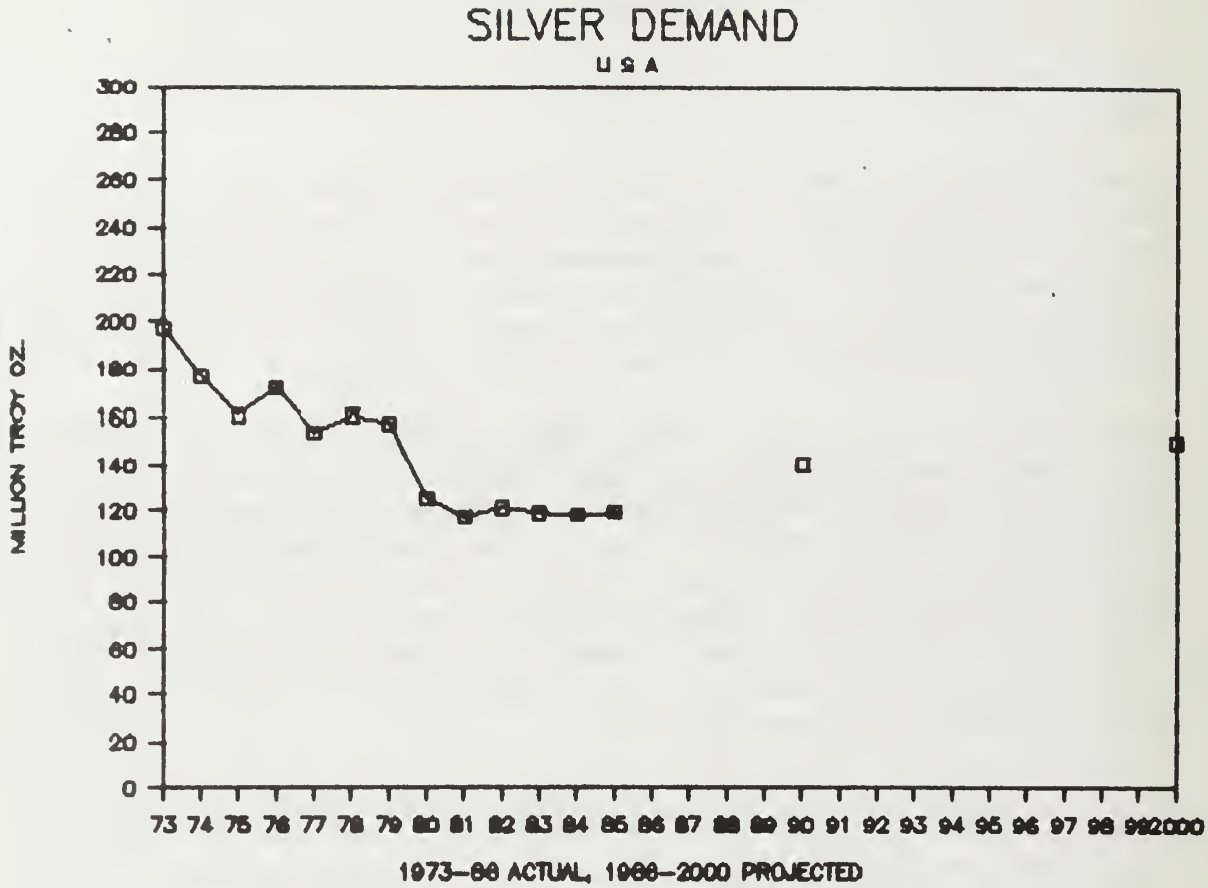
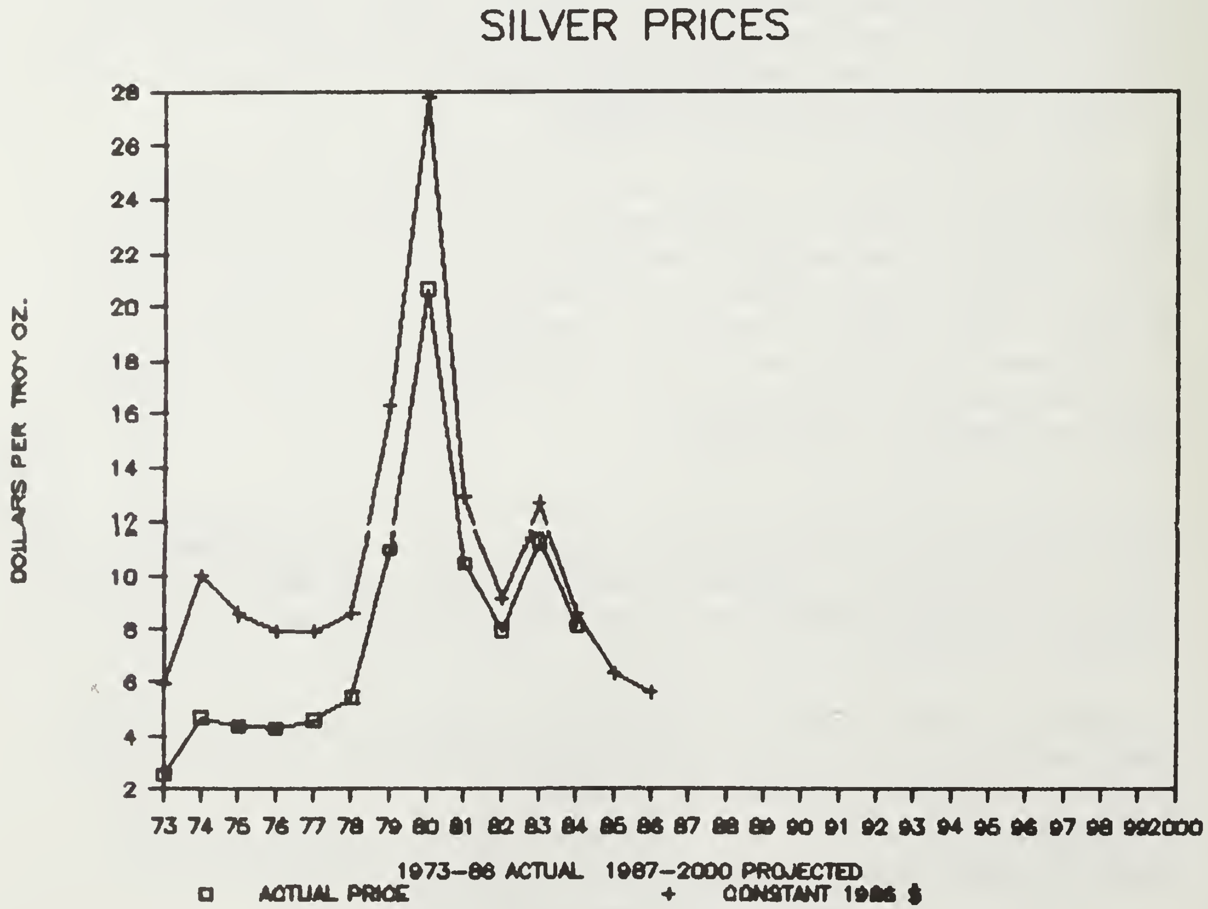


FIGURE 14



Completely apart from its industrial uses, silver has another important role as "poor man's gold." Its price tends to move with that of gold, although at a much lower level. However, the movements are not always in direct proportion, since industrial demand is a much larger component of the price of silver than that of gold. Gold, having much less of an industrial anchor, responds more directly to the public's perceptions of inflation and the value of the dollar. The currently declining value of the U.S. dollar should increase the price of gold and silver.

SUMMARY AND CONCLUSIONS

The broad trend of the real price of metals has been generally downward, reflecting the forces of supply and demand. The supply curve for metals has probably moved outward (increased) as mineral exploration and technology have combined to make huge tonnages of metals available at lower costs. (There is a parallel in agriculture, in the "green revolution").

The industrialized nations are, of course, the main consumers of metals (and energy) and as their economies have matured, the intensity of use of metals has declined. In addition, man-made substitutes have replaced metals in many applications, either because of lower unit costs or for technological requirements. In the meantime, the long anticipated surge of demand from the Less Developed Countries (LDCs) has not yet materialized, and there is no indication of it emerging in the foreseeable future. Thus, the demand curve for metals (a) has apparently not shifted outward at all, (b) has not shifted outward in the same proportion as the supply curve, or (c) may have shifted inward in the industrialized nations. Any one of these possibilities, coupled with the apparent outward shift of the demand curve would result in lower prices and demand for metals.

Regarding metals potentially recoverable from the waters of the Berkeley Pit, it appears that their present low prices and levels of demand will continue into the future.

TABLE 1

ALUMINUM DEMAND AND PRICES

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
AL DMD USA (000 MT)	5,941	5,625	4,079	5,196	5,649	6,111	6,030	5,223	5,209	4,811	5,442	5,227	5,174					7,500
$/LB MKT PR	0.26	0.43	0.35	0.41	0.48	0.51	0.71	0.76	0.6	0.47	0.68							
$/LB CONSTANT '86$	0.60	0.81	0.60	0.67	0.74	0.73	0.94	0.92	0.66	0.49	0.68	0.57	0.49	0.55	0.53	0.61	0.64	0.67

TABLE 2

COPPER DEMAND AND PRICES

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
CU MTL DMD USA (000 MT)	2,208	2,210	1,467	1,946	2,045	2,369	2,432	2,175	2,278	1,761	2,020							2,300
$/LB MARKET PR	0.60	0.77	0.65	0.70	0.67	0.65	0.92	1.01	0.84	0.78	0.77	0.67	0.67	0.63				
$/LB CONSTANT '86$	1.38	1.64	1.25	1.27	1.14	1.04	1.35	1.36	1.03	0.90	0.85	0.71	0.69	0.63	0.67	0.71	0.72	0.76

TABLE 3

MAGNESIUM DEMAND AND PRICES

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
MG TOTAL DMD USA (000 T)	1,122	1,161	1,108	1,052	1,038	1,082	1,134	916	916	693	792			
$/LB MARKET PRICE	0.38	0.75	0.82	0.92	0.99	1.01	1.09	1.25	1.34	1.34	1.38	1.46	1.48	1.48
$/LB CONSTANT '86$	0.88	1.60	1.59	1.68	1.69	1.61	1.60	1.68	1.64	1.54	1.53	1.55	1.53	1.48

TABLE 4

MANGANESE DEMAND AND PRICES

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
MN DMD USA (000 ST)	1,554	1,492	1,133	1,364	1,523	1,363	1,250	1,029	1,027	672	668		
$/LB MARKET PRICE (IN ORE	0.65	0.90	1.38	1.45	1.48	1.40	1.40	1.70	1.72	1.58	1.38	1.45	1.43
$/LB (IN ORE) '86$	1.51	1.92	2.68	2.64	2.53	2.23	2.05	2.28	2.11	1.82	1.53	1.54	1.47

TABLE 5

MOLYBDENUM DEMAND AND PRICES

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
MO METAL DMD USA (000 LB)	73,449	71,612	55,302	59,949	61,350	67,724	73,682	61,025	61,669	37,211	43,015	34,792	33,451	
$/LB (MO IN OXIDE)	1.92	2.24	2.74	3.26	4.02	4.86	6.07	9.36	6.4	4.1	3.64	3.59	3.25	3.12
$/LB CONSTANT '86$	4.46	4.77	5.32	5.95	6.88	7.75	8.89	12.57	7.84	4.72	4.04	3.82	3.35	3.12

TABLE 6

ZINC DEMAND AND PRICES

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
ZN DMD USA (000 MT)	1,474	1,311	1,331	1,298	1,154	1,154	932	951	1,146	869	1,005	1,215	1,095					1,200
$/LB MARKET PRICE	0.21	0.36	0.39	0.37	0.34	0.31	0.37	0.37	0.45	0.38	0.41	0.49	0.40	0.46	0.38	0.40	0.41	0.43
$/LB CONSTANT '86$	0.48	0.77	0.76	0.68	0.59	0.49	0.55	0.50	0.55	0.44	0.46	0.52	0.42	0.46	0.38	0.40	0.41	0.43

TABLE 7

SILVER DEMAND AND PRICES

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
AG METAL DMD USA (MM TR O	197.3	177.0	160.4	171.9	153.7	160.2	157.4	124.8	116.8	120.7	118.4	117.5	118.9	
$/OZ MARKET PRICE	2.56	4.71	4.42	4.35	4.62	5.4	11.09	20.63	10.52	7.95	11.44	8.14	6.14	5.59
$/OZ CONSTANT '86$	5.95	10.04	8.58	7.93	7.90	8.61	16.24	27.71	12.88	9.15	12.69	8.67	6.33	5.59

REFERENCES CITED

Engineering and Mining Journal, annual summaries, March 1984, 1985.

Sonderegger, John, 1986. "Butte Mineflooding and the Berkeley Pit," Headwaters Research Institute conference paper, January 1987.

U.S. Department of the Interior/Bureau of Mines, "Mineral Facts and Problems," 1985.

U.S. Department of the Interior/Bureau of Mines, "Minerals Yearbook," preprints, 1986.

World Bank, 1986, Summary of survey of metal price forecasts by industry experts. (Personal communication.)

SUPERFUND AMENDMENTS OF 1986

A VISION FOR MONTANA'S ECONOMIC FUTURE

By

Steve Browning

Mr. Steve Browning, an attorney now based in Helena, Montana, has extensive experience in Congressional decision making, as the person in charge of the staff of Senator Max Baucus. He is considered quite knowledgeable of the network of staff relationships in our nation's capital.

BACKGROUND

Hazardous wastes are a growing problem of alarming proportions. As the world's most heavily industrialized nation, America has produced some of the most toxic hazardous waste existing anywhere on the globe. The Federal Office of Technology Assessment recently predicted that hazardous waste cleanup will be a $15 billion per year industry in less than ten years. To put this in perspective, the American coal industry today generates less than $15 billion annually. In short, the emerging hazardous waste industry is in its infancy, and Montana should consider now whether it can become a leader in that industry. I believe it is possible. Here is why.

Montana is strategically placed to be a key player in the toxic waste detoxification and cleanup industry. The traditional shortcomings that our state has in spawning most industries are not applicable here. We are far from potential markets, subject to high transportation costs, sparsely populated, undercapitalized, and just generally cold. But these factors are not impediments to Montana emerging as a major center of innovation and excellence for identifying, detoxifying, and controlling hazardous wastes.

The emerging hazardous waste detoxification industry is essentially a child of the federal government. Congress charted that course with the historic enactment of CERCLA (the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC 9601, et seq.) Our Congressional delegation is nicely positioned to support efforts to nurture the emerging hazardous waste detoxification industry in Montana. Our representatives hold senior positions in many of the committees with jurisdiction of this issue.

Montana State University is nicely positioned to become a Center of Excellence on research and development projects relating to hazardous waste identification, measurement, and detoxification. MSU's chemistry faculty includes world-class experts, and the department has state-of-the-art technical equipment and resources that can be brought to bear on hazardous waste problems. The same can be said for MSU's School of Engineering. Equally importantly, the faculty and administrators of MSU perceive the hazardous waste challenge as one of the highest on their agenda. Montanans pride themselves on their environment, and MSU policy makers have sought to pursue this shared conviction by establishing MSU as one of the premier educational institutions in the country that can do work on such environmental research issues.

The capability of the residents of the Bozeman area to become key players in the hazardous waste detoxification industry transcends the existence of the university research capability. One of the potentially world-class businesses dealing in the subject of hazardous waste detoxification is MSI Detoxification, Inc., a new company that recently moved to Bozeman. (See Appendix A to this paper) MDI expects to be a $450 million per year participant in the hazardous waste industry before the year 1995. Significantly, MDI recently announced its plan to be the prime tenant in the Science and Technology Park development that is being built on MSU Foundation land located east of the campus.

The Superfund Amendments and Reauthorization Act of 1986 (SARA) poses significant opportunities to stimulate, nurture, and install Montana's potential position as a Center of Excellence for research, development, and commercialization of procedures to detect and detoxify hazardous wastes. A brief review of the key SARA provisions that bear on this matter follows.

SUPERFUND ACT AMENDMENTS ON RESEARCH AND DEVELOPMENT

The new amendments can provide a number of apparent opportunities that Montana can capitalize on in its pursuit of a Center for Excellence for hazardous waste identification and detoxification. The opportunities are present both for our state's university system and for the newly established companies, such as MDI, that are preparing to become a part of the expected mushrooming growth in the detoxification waste industry.

The principal areas of opportunity exist in the research and development realm. Three federal agencies are responsible for such research under the amendment: HHS, EPA, and DOD.

Health and Human Services

Section 209 empowers the Secretary of HHS to establish a "basic university research and education program." A similar program is required to be set up in EPA.

The Secretary of HHS is required to establish a basic research and training program through grants, cooperative agreements and contracts that, among other objectives, will pursue the following:

1. Methods to assess the risks to human health presented by hazardous substances;

2. Methods and technologies to detect hazardous substances in the environment and basic biological, chemical, and physical methods to reduce the amount and toxicity of hazardous substances.

Environmental Protection Agency

The EPA Administrator is also authorized to carry out a program of "research, evaluation, testing, development, and demonstration of alternative or innovative treatment technologies . . . which may be utilized in response action to achieve more permanent protection of human health and welfare and the environment."

Department of Defense

Finally, the Secretary of Defense is authorized to carry out a research and development program on the following items:

1. Means of reducing the quantities of hazardous wastes generated by activities and facilities under the jurisdiction of the Secretary;

2. Methods of treatment, disposal, and management (including recycling and detoxifying) of hazardous wastes . . .

3. Identifying more cost-effective technologies for cleanup of hazardous substances . . .

HHS HAZARDOUS WASTE ADVISORY COUNCIL

The SARA amendments also mandate the Secretary of Health and Human Services to appoint an Advisory Council that will consist of representatives from a variety of areas, including institutions of higher education and the toxic waste management industry.

The HHS Secretary is responsible for issuing a plan on or before July 3, 1987, that will "include priorities for . . . research and training relevant to scientific and technological issues resulting from site-specific hazardous substance response experience." The Advisory Council is required to be provided "an opportunity to review and comment on the plan and priorities and assist appropriate coordination among relevant federal agencies . . ."

The Advisory Council requirement presents an excellent opportunity for highlighting Montana's interest in pursuing a hazardous waste detoxification agenda. Every effort should be made to have at least one Montanan appointed by Secretary Bowen.

I have spoken to William Tietz, President of Montana State University, asking his interest in participating on the Advisory Council. Dr. Tietz is most interested and would be willing to serve. He further indicated that he has espoused for several years his belief that Montana can and should be more actively involved in the national movement to identify and detoxify hazardous waste. He also suggested that Dr. Edward Dratz, a member of the MSU faculty and Director of Research for MSI Detoxification, Inc., would also be an excellent representative from either the toxic waste management industry or an institution of higher education.

DEMONSTRATION ASSISTANCE PROGRAM

As part of the EPA Administrator's new responsibilities for research and development, there is a requirement to establish a demonstration assistance program which will be used to demonstrate projects utilizing "alternative or innovative technologies, testing and evaluation of innovative technologies, or innovative technology demonstration projects." The Administrator is required to "publish by January 3, 1987, a solicitation for innovative or alternative technologies at a stage of development suitable for full-scale demonstrations at sites at which a response action may be undertaken . . ." It may be appropriate to seek a site in Montana that could be used as a basis for demonstrating the development technologies that are now underway at MSU and MSI Detoxification, Inc.

UNIVERSITY HAZARDOUS SUBSTANCE RESEARCH CENTERS

The SARA Amendments also require the EPA Administrator to "make grants to institutions of higher learning to establish and operate not fewer than five hazardous substance research centers in the United States." These would appear to be government-funded "Centers of Excellence" that would be pursuing the cleanup of hazardous wastes and the science and engineering research and development necessary to achieve identification and detoxification of hazardous wastes. This may be an area worth pursuing for Montana State University and/or Montana Tech.

CHARLES L. FISHMAN, P. C.
ATTORNEY AT LAW
WASHINGTON, D. C. 20036

SUITE 502
1717 K STREET, N.W.

TEL. 202/293-0150
FAX. 202/293-0147

MEMORANDUM

TO: Steve Browning

FROM: Sheryl Rutledge

SUBJECT: Hazardous Waste Research Centers

DATE: December 17, 1986

As you may remember, Ron Cooper of Senator Baucus' office mentioned that there was some type of provision in the Superfund law which would allow Montana to establish hazardous waste research centers. He thought that it had something to do with Battelle labs and Congressman Wyden. I have done some research into the issue and have found that both Congressman Swift and Congressman Wyden introduced provisions which may be of interest to MDI:

- The Superfund Amendments and Reauthorization Act of 1986 (Report 99-962) establishes a Pacific Northwest Hazardous Substance Research, Development and Demonstration Center in Section 118, "Miscellaneous Provisions," Paragraph (0) (p.52).

The amendment was introduced by Congressman Al Swift (D-2nd-Washington) at the urging of Battelle labs. Battelle has a facility in Swift's district as well as in the district represented by Congressman Sid Morrison (R-4th-Washington).

At the time the amendment was introduced in the conference on Superfund, Congressman Swift approached Senator Max Baucus to obtain his support for the establishment of the research center. In order to do this, Congressman Swift stipulated that the center would "enter into agreements with universities located in the States of Washington, Oregon, Idaho and Montana in order to carry out the purposes of the Center" (Section 118 (0) (3) (B). The permanent research facilities, however, are to be located in Benton County, Washington (4th District) and Clallam County, Washington (2nd District). Although the statutory language refers to universities, the report of the managers indicates that Battelle is not limited to contracting only with these bodies. The report states that EPA "may also negotiate arrangements with federal and state agencies and industry." (p. 236)

Battelle, in a sense, would be the "project manager" for the research and would manage it from its facilities in Washington. Battelle is specifically designated as the lead organization by the langauge of the amendment: "For the purpose of operating the center, the Administrator is authorized to enter into contracts and cooperative arrangements with, and make grants to, a non-profit private entity as described in Section 201(i) of Public Law 96-517, which entity shall agree to provide the basic technical and management personnel."

It is my understanding from talking to the Washington Representative for Battelle that the amendment did not intend that any new facilities be constructed, only that research be conducted at presently existing facilities. Battelle intends to hold a conference at the beginning of the year and will invite universities and other parties interested in participating in the research to attend. They have not, however, scheduled an exact date or location.

According to Battelle, although the center is "authorized " there was no money appropriated by the legislation for its operation. Battelle intends to attempt to correct this in the next session of Congress by introducing an amendment to an appropriations bill which would fund the research. They expect that EPA and the Administration will not act unless there is a specific appropriations bill. In addition to the funds obtained from the federal government, Battelle intends to allocate funds of its own to the research project.

I explained to the Battelle representative that our clients were potentially very interested not only in the briefing session to be conducted next year but in attempting to see that money was appropriated for the project. He promised to keep me informed of his progress and welcomed our assistance when we get to the appropriations process.

o The Superfund Amendments and Reauthorization Act of 1986 establishes four programs for Research, Development and Demonstration in Section 209 (p.101).

A second section on research, development and demonstration was added to the bill by Congressman Wyden (D-3rd-Oregon). Section 209 would "establish a comprehensive and coordinated federal program of research, development, demonstration and training for the purpose of promoting the development of alternative and innovative treatment technologies that can be used in response actions under the CERCLA program, to provide incentives for the development and use of such technologies and to improve the scientific capability to assess, detect and evaluate the effects on and risks to human health from hazardous substances.

One program entitled "Hazardous Substance Research and Training" would be established in the Department of Health and Human Services to conduct basic research and training (Paragraph (a), page 101). Although the grant is to be awarded to a university, the university may carry out the research with "persons involved in the detection, assessment, evaluation and treatment of hazardous substances," among others. An Advisory Council would be established to aid in the implementation of this section.

A second section entitled "Alternative or Innovative Treatment Technology Research and Demonstration Program" empowers the Administrator of EPA to "carry out a program of research, evaluation, testing, development and demonstration of alternative or innovative treatment technologies (Paragraph (b), page 103). The Administrator is allowed to make grants to "persons, public entities and non-profit entities;" cost sharing arrangements are to be preferred when awarding contracts. The Administrator is to select 10 sites proposed by the applicants at which their innovative technology will be applied and evaluated.

A third section entitled "Hazardous Substance Research" empowers the Administrator of EPA to conduct and support research of the effect of hazardous substances on health and the detection of hazardous substances in the environment (Paragraph (c), page 107). Although the Administrator is to coordinate both with HHS and the Advisory Council, the research is independent of that conducted by HHS.

A fourth section entitled "University Hazardous Substance Research Centers" would establish hazardous research centers at universities (Paragraph (d), page 107). It would empower the EPA administrator to establish and operate not fewer than 5 and up to 10 hazardous substance research centers. Any university may apply to the Administrator. The awards are to be given to universities located in areas with hazardous waste problems. The university would have to contribute $100,000 a year of its own money.

The funding for these four proposals is listed among "Uses of the Fund," Section III, (d) (10) and (n). Congressman Wyden's staff believes that because the language does not specifically require an appropriation, no specific appropriation is required before EPA can fund the program. EPA, however, has taken the position that it will need a specific appropriation from the fund account in order to allocate the money. This means that whether or not the money is legally available, appropriations legislation will have to be passed before EPA will begin allocating money to the projects. Accordingly, whether MDI wishes to pursue opportunities under either the Swift or Wyden amendments, appropriations legislation will be needed before these resources become available.

ORGANIZATIONAL CONCEPT

HEADWATERS RESEARCH INSTITUTE

By

John Driscoll

Commissioner John Driscoll, a member of the Montana Public Service Commission, has advanced degrees in Economic Development and Energy and Environmental Policy from Columbia University and Harvard University, respectively.

INTRODUCTION

On December 1, 1986, the final Articles of Incorporation and Bylaws for the Headwaters Research Institute were submitted to the Montana Secretary of State. This paper is to briefly outline the principal concepts that underlie the organization's formation and, by attachment, state the mission of the organization for this "Reindustrialization Project."

The major concepts that will be discussed in turn are: 1) The economic "driver" and 2) the "RC&D community self development" approaches to economic development; 3) the national need to apply advanced technology to basic human and industrial problems; 4) a new technological era that may see an integrated approach to development processes so that harmful waste is addressed internally to the production process rather than at "the end of the pipe;" 5) the chance to turn a perceived problem into an economic opportunity; 6) the need to avoid past mistakes of history by establishing a structure for local initiative and direction; 7) the need to develop a systematic organization and synthesis of technologies that will keep the Clark Fork River Basin clean and wealth being created long after the Superfund is exhausted; 8) the need to coordinate the locality's, state's, and region's scarce technological resources; 9) the need to encourage commercial spin-off activity; 10) the need for a public interest-driven coordinator of various agency activities; and 11) the need for an organization that will look for an optimal solution to all related problems, rather than seize on one solution because of grant money availability in one area or profitability in another. These are addressed in detail in the following section.

The Economic "Driver"

President Kennedy's goal to put a man on the moon in the 1960s or the U.S. Congressional effort to build parallel transcontinental railroads in the late 19th Century are two examples of seizing upon missions barely within reach, organizing scarce resources toward them, and using them as massive drivers in critical parts of the national economy. The mission to lead the development of the Butte Hill is barely within our reach, but achievable. The very difficulty of the mission tells us its impact as a regional economic "driver."

RC&D Community Self Development

The truly effective economic development programs for this region have traditionally been the Resource, Conservation, and Development community self-help programs. Therein, an individual or group with their "good idea" asks the advice and assistance of other members of the same community to learn the wisdom of local experience. This idea began as an RC&D Project with a single sponsor. Credible people with relevant experience have since helped to bring the idea to its present stage in much the same way that a group of farmers and ranchers have often helped a fellow farmer with his special project. The success of the project benefits all. Thus the need for, and existence of, a western tradition of cooperation. Considerably more collaboration and cooperation will be necessary before this mission is accomplished, but it is here in the regional technological community to be had.

Advanced Technology Applications

Nationally, we pride ourselves on our advanced technology (information age, biotechnical age, etc.), while locally we scold ourselves for being "anti-business," a word that has prevented able Montanans from communicating intelligently about the nature of our real problem and some possible solutions. Ironically, it appears that every part of the country is up against the same problems in their basic industrial sectors and similarly wasting their time gnashing teeth about the "anti-business climate." It appears more accurate that our country has been unable to rapidly translate its edge in advanced technology into wealth-creating activity in the basic industrial sectors. This very problem has been an important topic of discussion among members of the National Academy of Sciences. This project is intended to bridge that gap, and to bring existing or newly developing technology to bear in new combinations on traditional problems. On the ore processing side of the mission we are talking about breathing new technology into industrial activity that was rather unique to the Butte - Anaconda area, or at least unique to an industry that has of late been on very hard times. On the water cleaning side of the mission, we are talking about developing or applying new technologies in an area that is rapidly gaining national significance: the cleaning of low-grade non-organics from water.

Integrated Approach Concept

The mission of this effort has been stated specifically to encourage redevelopment that will address potentially harmful waste in ways that are internal to the production processes. If we treat this new industrial effort as one that claims clean air and water as important and valuable products, we are more likely to attempt to achieve international market competitiveness without subsidizing that competitiveness with a dirty environment or unsafe work place. The presence of Superfund incentives to actually develop technologies for mitigating environmental problems and cleaning up the Butte Hill give us a better chance of actually producing clean water as an actual product. Beyond the immediate, however, it is clearly becoming an international goal to develop management styles and organizational approaches that will synthesize technologies to maximize wealth creation and minimize harmful side effects.

Economic Opportunity

This is a major chance to turn a perceived problem into an opportunity. It's the old timers in Montana who first indicated their concern that we may be missing the chance to use the unchained water forces in the Butte Hill to accomplish old goals faster and cheaper as well as to develop new goals. These same veterans of the "Richest Hill on Earth" are as mindful of the enormous wealth that still waits to be converted in the environs of the Berkeley Pit. Certainly the Berkeley Pit is a unique site for water-cleaning technical development. Perhaps the presence of water also represents an opportunity to take some metals out of the rock more cleanly and efficiently. Likely the approach to the opportunity will be much more convoluted, but it seems imperative to at least begin the creative and innovative processes.

Local Initiative Structures

One needs little familiarity with Montana, and Butte in particular, to understand the history of major decision making that was made in far-away board rooms, be they San Francisco, St. Louis, or New York. The extractive industry bred a lifestyle that was paradoxically independent at the individual level, but very dependent at the economy level. New players in the Butte drama will replace names like Standard Oil and ACM with names like ARCO and EPA. The goals will be Superfund cleanup, but the dependency on external decision makers could be essentially the same unless a competent local organization is present to help guide the interplay of decisions that will certainly have great influence on life in Montana through the end of the century. The Headwaters Research Institute will hopefully serve as one of those competent local initiatives.

Organization

The Bylaws of the Headwaters Research Institute set in motion a system of appointments by various branches of government that remove the dependence of the organization on personalities. Important public institutions have the opportunity to alter appointments from year to year, as the research missions of the Institute change. The majority of appointments go to institutions that represent various levels of constituencies for the Institute to insure that those public constituencies are represented properly, thereby serving the public interest and insuring continuing and flexible public accountability.

Resource Coordination

The scarce technical resources of the region are represented on the Board in the form of appointments by governmental institutions that control technical capability and by important non-profit research capability in the private sector as well. These appointments tie the organization to what is happening in the research sector across the board, thereby avoiding duplication.

Commercial Spin-Off Activity

Since this is a non-profit corporation, the real wealth creation activity must come from the application of developed or modified technologies to raw situations by the private sector. This transition may occur with the assistance of transition-type organizations, such as the Butte Business Incubator or the Butte Local Development Corporation, or it may occur with the use of joint ventures by Headwaters Research Institute. Technology protected to the degree that it can be licensed serves both to generate income to the research organization and to make the application of the technology more attractive to the private sector.

Agency Coordination

There appears to be a need for a purely public-interest driven organization to step into some Berkeley Pit-related activities, where private liability or the limitations of agency jurisdiction prevent timely systematic initiatives. Boats, for example, are necessary for good sampling. What agency in Montana (with jurisdiction) has the need for boats? The water needs to be cleaned, but what agency has the mandate to advantage Montana of the opportunity to develop such technology right here in Montana (rather than, as inevitably happens, somewhere else?) To accomplish beneficial activity with the water seems to dictate that a right to the use of the water be acquired. What agency can do that? What private corporation with deep pockets wants to call the water its own with Superfund liability hanging over its head? While agencies are performing the direct enforcement roles with which they are properly charged, who is devising strategies to clean the water that blend with the entire area's unique combination of sunken resources and opportunities, and that will last longer than Superfund monies and maybe even as long as the problem, or even the river drainage? An innovative organizational structure is needed to get the job done; Headwaters Research Institute is oriented to that purpose.

Optimal Solutions

The most profitable opportunity to, for example, extract metals from the pit water may not be the best course of action. Conceivably a profitable course of action, if not critiqued, might result in even greater long-term cleanup costs. Given that we are trying to minimize waste, and measuring clean water as a desirable product, the best solution is an optimal one. Profit-making corporations will not seize the optimal solution in this situation. Rather they must each be part of an effort to generate a combination of activities that yields an optimum solution. An organization with a non-profit motive is best suited to such a task.

SUMMARY

The mission of this project is attached, as is the initial makeup of the Board of Directors for the organization. The goal is formidable, but achievable if there is enough will, creativity, cooperation, and professionalism. Failure is not possible, because we have begun the attempt. That by itself is the measure of success. Mission accomplishment is as possible in Montana as anywhere in this country.

ACTION PAPER

NO. 86-11

1. Purpose

This Action Paper is to state the mission of Headwaters Research Institute for its activities under the "Reindustrialization Project".

2. Authority

This activity comes under the Institute's Articles of Incorporation, ARTICLE III, Purpose (a):

> "To aid the development of new technology, and the innovative application of existing technologies, in manners that will appropriately enhance the long-term quality of life on the land."

3. Project Mission Statement

"Lead and perform research and development to assist the redevelopment of the Butte, Montana mining region so that competitive production processes and waste control are addressed simultaneously and in an integrated manner. This will require an integrative management approach and a synthesis of technologies that enhances efficient ore production and processing on the one hand, and clean air and water on the other. For this project clean air, water, and new technology are considered economic products in importance equal to traditional and new mineral products and services."

4. Execution

a. An expanded steering committee will generate the initial direction;

b. An interim project team will complete an action plan, based on the steering committee direction;

c. A technical advisory group, comprised of some members of the Board of Directors and technically oriented advisors, including some potential subcontractors, will review the plan;

d. An operational advisory group, comprised of the policy committee of the Butte Business Incubator, will be asked to review the plan;

e. The Board of Directors will give final approval, and hire project management assistance as well as task contractors as are necessary.

5. Cooperation

This mission will be best served by maintaining the highest level of scientific, technical and management proficiency. This also requires that duplication or competition be avoided where adequate products, services, and research already exist or are in progress.

6. Co-venturing

Cooperative ventures with large research laboratories may be used if the effort fits the project workplan, or otherwise enhances the project mission.

Pooling funds, talent, facilities, and information will multiply the effectiveness of the collaborative resources guided by the Headwaters Research Institute Board of Directors. Co-venturing may be a way to, in addition, attract a diverse array of competent investigators able to further our accomplishment of the project mission.

7. Contract Work

Contract work by Headwaters Research Institute will be accepted only if it builds upon the work that the Institute plans and executes towards its mission.

8. Commercialization

Significant development benefits will result when technologies developed or modified by this effort are used commercially by the profit-making sector. Accordingly, Headwaters Research Institute will insure that such products are available in a timely manner.

9. Financial Resources

The resources that will be directed at this mission will consist of the collaborative efforts of able individuals and organizations, grant monies, income from the sale of prototype products and byproducts, licensing arrangements, contract work, publications, and, perhaps, the sale of cleaned water. Such income will be reinvested in the organization for further research toward this mission and the goals of Headwaters Research Institute.

10. Periodic Review

An annual review of the mission and the performance of this organization in light of the mission will be prepared for each April meeting.

BYLAWS EXTRACT

HEADWATERS RESEARCH INSTITUTE

Section 3. Qualifications. The board shall at all times consist of a majority of publicly accountable individuals. The qualifications of the board shall be as follows:

a. Legal Counsel;

b. A representative of the Mile High Conservation District (public);

c. A representative of the Executive Branch of Montana State Government, approved by the Governor's Office (public);

d. An official elected to a position in Montana's State Government, and chosen by the Headwaters Board (public);

e. A representative of the City of Butte / Silver Bow selected by the Office of the Chief Executive (public);

f. A member of the teaching or research faculty of the Montana University System, selected by the Vice President for Research at Montana State University (public);

g. A member of the teaching or research faculty of the Montana University System, selected by the Director of Research at the Montana School of Mineral Sciences and Technology (public);

h. A representative of the Montana Energy Research and Development Institute (non-profit R&D);

i. A representative of Battelle's Pacific Northwest Laboratories (non-profit R&D);

j. A representative of the National Center for Appropriate Technology (non-profit R&D); and

k. A representative of the Clark Fork Coalition (non-profit public interest).

Approved by Board Action November 27, 1986
May be modified by Board action.

OUTLINE OF A CONCEPT FOR WATER RECLAMATION/MINERAL RECOVERY FROM THE BERKELEY PIT IN BUTTE

By

Walter Juda

Prototech Company

Dr. Walter Juda, President, Prototech Company, has many years of experience in water cleanup as well as electrochemical processing of inorganics.

BACKGROUND

At a meeting on September 16, 1986, organized and chaired by John Driscoll, the following processes were outlined as an example of a scheme worthy of investigation, with the goal of expanding Butte's mineral industry as well as contributing to solving Butte's water problem.

By way of background, it appeared at the meeting that the rate of increase of the water level in the Berkeley Pit has been slowing down sufficiently not to constitute a flooding threat for some years. Rather than focusing, therefore, merely on the water problem, there appears to be sufficient time to consider coupling water reclamation with mineral recovery in the hope that a profitable combination of processes involving preferably new technology can be put in place.

CONCEPTS

Here is a summary of process concepts for one such combination.

1. Assume that from one or more shafts preferably zinc-rich waters (of course including other dissolved minerals) can be drawn in sufficient quantity for a zinc tankhouse producing at least 50,000 tons of zinc per annum for a reasonable number of years. (Would this, for example, be the case of pumping CA 30,000-35,000 gpm from 784 feet below water surface (2137 feet)? These waters would be pumped into a first reservoir to be built adjacent to the pit. Suspended solids, if any, may settle out here.

2. Taking advantage of the long winter in Butte, ice would be formed in this reservoir and would be mechanically transferred to a second reservoir, the ice being mineral-free except for a small layer of adhering mother liquor. Of the order of perhaps one-half of the total water, the "blow-down", remains in the first reservoir.

3. This first blow-down is apt to be insufficient in zinc concentration for economical recovery thereof. Thus it would be subjected to a second treatment, such as reverse osmosis or electrodialysis, resulting in additional fresh water to be added to the (to be melted) ice in the second reservoir. The now perhaps ten-fold concentrated zinc-bearing second blow-down would constitute the feed to the zinc plant.

4. The zinc plant would comprise one purification section to prepare the appropriate zinc sulfate feed for the tankhouse, most of that section presumably utilizing known chemistry. For example, controlled lime addition would precipitate iron and aluminum

hydroxides; filtration and/or settling would yield a clear zinc sulfate solution for further purification.

The purified zinc sulfate would then be subjected to electrolysis in the tankhouse, involving the novel hydrogen diffusion anodes now undergoing tests in Europe in a cooperative effort between Prototech Company and two major German companies. It is hoped and anticipated that this process at the expense of hydrogen will be proven in Europe within the next few years, prior to its introduction in this country.

5. The new process requires significant amounts of hydrogen which, in Butte, may perhaps be derived inexpensively from such low-cost fuel as Exxon's sulphur-containing petroleum coke available nearby at Billings, Montana. Hydrogen could be manufactured from such coke, for example, by high-temperature reforming followed by desulphurization.

CONCEPT PAPER

PROPOSED WATER CLEANUP
OF THE BERKELEY PIT

Submitted To:

Dr. Lloyd Berg

Department of Chemical Engineering

Montana State University

By

Roberta Beery
Terry Davis
Teri Henderson

Dr. Lloyd Berg, Chairman, Chemical Engineering Department, Montana State University, has an extensive track record in applying new ideas to difficult engineering problems. With his support two teams of graduate students have suggested some ideas for the water/mineral question in Butte.

ABSTRACT

Contaminated mine water is flowing into the Berkeley Pit at a rate of 7.2 million gallons per day and threatens to destroy the quality of water in the Butte water table. If the water continues to rise at the current rate of 10 feet per month, it will enter the rock strata in approximately 10 years. Geologists have predicted that this rock strata is part of the natural aquifer and will allow the mine water to contaminate the local water table.

A reverse osmosis plant will process 8 million gallons of the mine water per day. In doing this, it will produce 800,000 gallons of concentrated brine per day. The plant contains one stage of 1,200 elements and will be operated at 225 psi.

The brine produced by the plant will be combined with 15.5 million pounds of coal to form a coal slurry. This slurry will then be charged to a 600 MW generating plant much like Unit Number 4 in Colstrip. The contaminates in the brine will then be removed with a scrubber system.

Power produced by the generating plant will be sold at a price of $00.044 per KW hour to offset the operating cost of $00.04 per KW hour. It is estimated that the power plant will cost $800 million and the reverse osmosis plant around $7.6 million to construct and put into operation.

INTRODUCTION

The Berkeley Pit is a large open pit copper mine located in Butte, Montana. This pit along with its two mine shafts, the Kelley and Belmont, have been mined since the turn of the century by the Anaconda Company. Through the years the shafts and the pit floor have been mined to depths below the water table. Consequently, the Anaconda Company had to continuously pump the mines free of water.

Mining ceased in April 1982, and the pumps were shut off. This allowed the shafts and the pit to fill with water. As of November 1985, the water in the pit was 425 feet deep (see Figure I). The water level continues to rise in the pit at a rate of 10 feet per month and it has been estimated that some 7.2 million gallons a day are flowing into it.

This water poses a serious threat to the water table in Butte and any downstream rivers. The water in the pit has a pH of 2.6 and contains many contaminates. Some of the more noteworthy are as follows: zinc, arsenic, sulfate, aluminum, cadmium, iron, and phosphate. Geologists have found a rock strata 100 feet above the water surface that may

CROSS SECTION LOOKING WEST

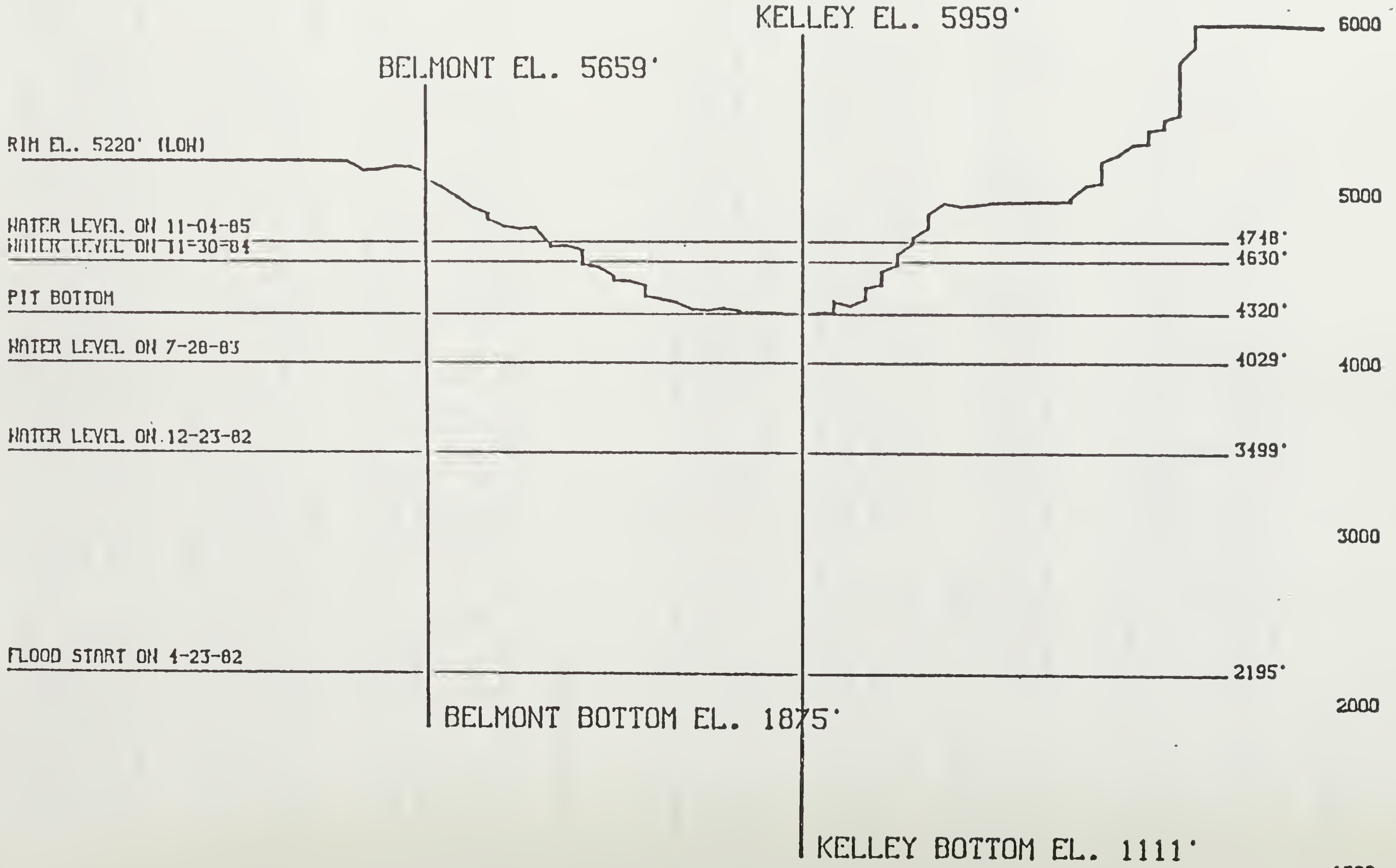


FIGURE I CROSS SECTION OF BERKLEY PIT

have been the location of the previous aquifer. If the water reaches this strata, it will enter Butte's water table. This would spell doom for the environment of Butte and any downstream rivers.

This study proposes prevention of this disaster with a reverse osmosis plant, designed to purify a portion of the water and concentrate the rest. The concentrate, or brine, would contain all the contaminates in the water and would be combined with a coal stream to form a coal slurry. The slurry would be burned in a coal-fired generating plant to produce electricity, and the contaminates would be removed in the scrubber system in the flue. The proposed diagram is shown in Figure II.

SOLUTION

In order to keep up with the inflow, the contaminated water will be pumped out of the pit at a rate of 8 million gallons per day. The initial pumping station equipment will be constructed of stainless steel to withstand the acidity of the water. As shown in Figure III, the pH of the water will be increased to about 6 by introducing lime into the stream. When the lime is added to the stream, most of the metals precipitate out. These solids must be removed so that the reverse osmosis membranes do not foul. To accomplish this, the solution is pumped into gravity thickeners where the solid material settles to the bottom and the clear liquid is decanted off the top. The sludge is now continuously scraped off the bottom and pumped back to the pit. The clear liquid from the thickeners is still highly concentrated with other soluble materials. These materials will also precipitate out and foul the membranes once the solution is concentrated with reverse osmosis. Therefore, sodium hexametaphosphate, a precipitate inhibitor, is added to deter this action and prevent any fouling. With the aid of this inhibitor, it is estimated that 90 percent of the solution can be removed as pure water.

The solute concentrate of the feed stream was determined from an analysis of the pit water and found to be 0.065 moles per gallon of solute. This stream will be pumped into the reverse osmosis plant, with an applied pressure of 225 psia. The theory of reverse osmosis is explained in a separate section following the conclusion.

The final product streams will amount to 800,000 gallons per day of concentrated brine and 7.2 million gallons per day of clean water. The brine exiting the reverse osmosis plant will be combined with 70 weight percentage coal (7775 tons per day) to make a slurry to fuel the electrical generating plant. The proposed plant will be modeled after the current generating plant, Colstrip 4, as it is a state-of-the-art plant. A general description of a coal-fired electrical generating plant is found in the theory section. The system flow processes are shown in Figure

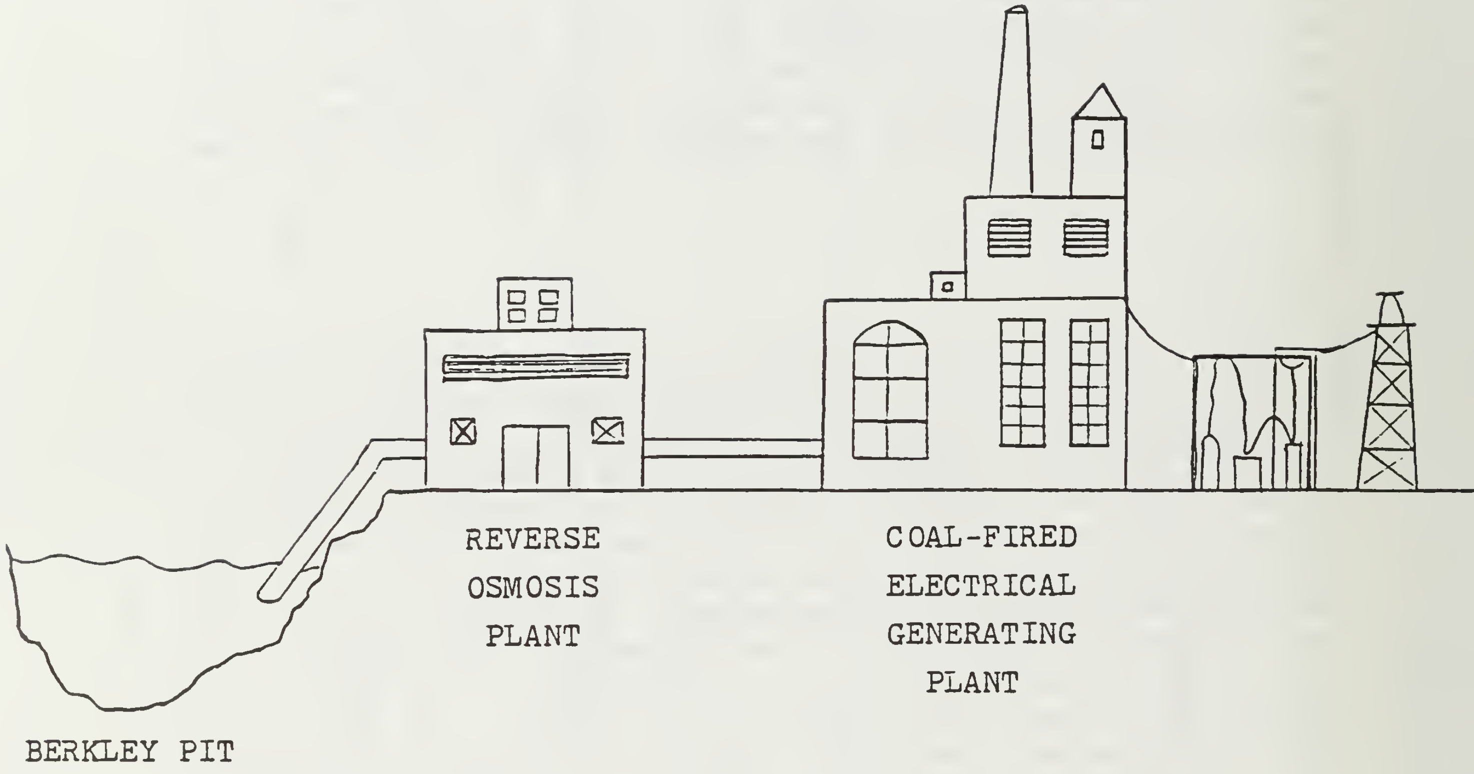


FIGURE II PROPOSED CLEAN UP PLANT

III. Colstrip 4 requires 9,600 tons per day of coal with a heating value of 8600 BTUs per pound. This would supply 1.65×10^{11} BTUs of heat per day. For the proposed plant, 6.5×10^{9} BTUs per day are required to evaporate the brine water. This must be subtracted from the 1.33×10^{11} BTUs per day supplied by the coal to give 1.27×10^{11} BTUs per day of heat available for power generation.

Colstrip 4, operating at 86 percent efficiency, produces 750 MW. The resulting power output for the suggested output would then be 600 MW. This power will be utilized by both plants and the remainder sold and put into the power grid for distribution to customers.

The capital investment for the coal plant has been estimated at $800 million. That of the reverse osmosis plant will be around $7.6 million. These costs are only estimates. The price of the reverse osmosis plant was determined using the basic equipment costs and a scale up. The generating plant is based directly on the cost of Colstrip 4. These calculations can be found in the Appendix to this paper.

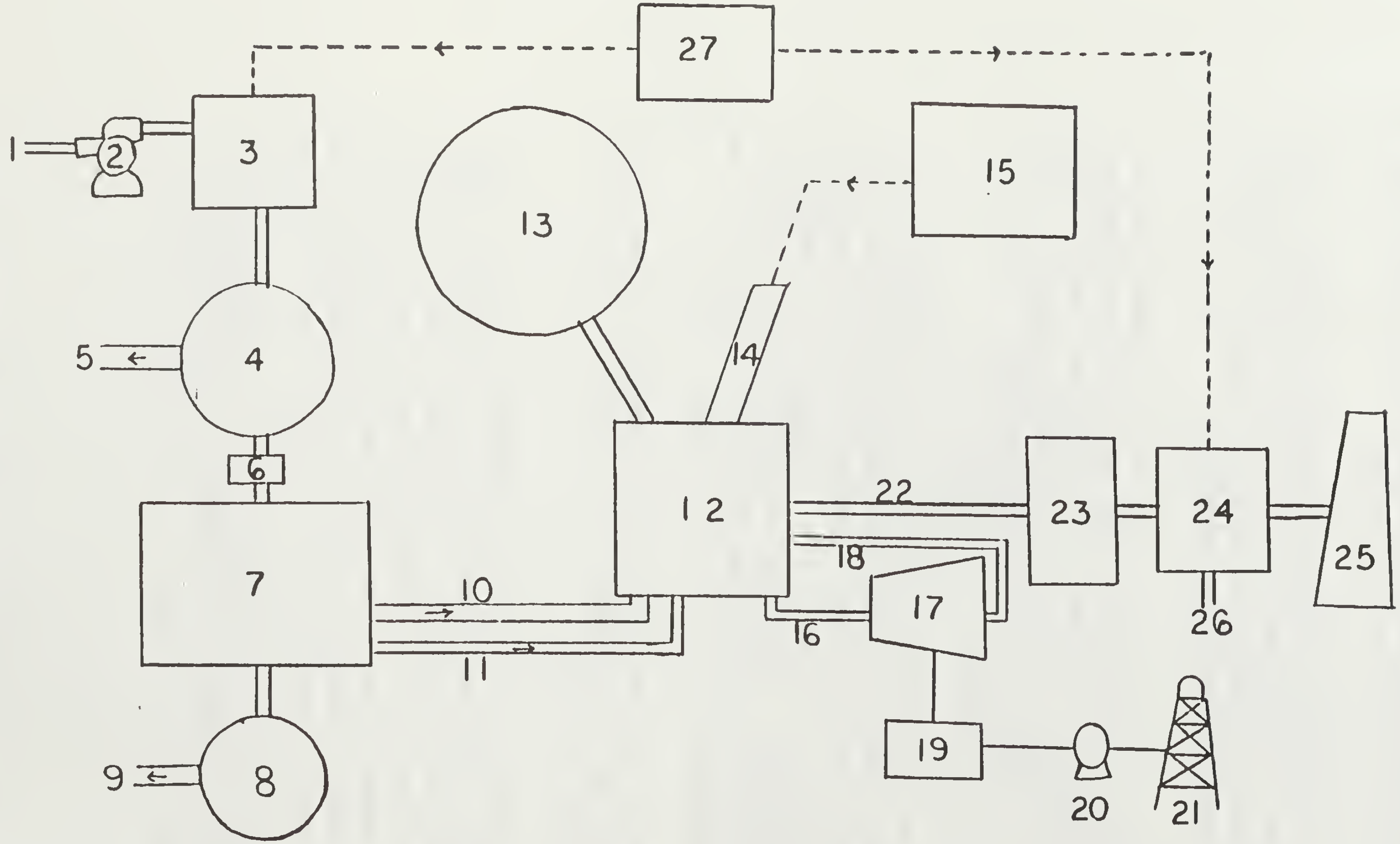
Coal for the plant will cost $22.50 per ton and will be delivered from Colstrip via a unit train. Labor is readily available in Butte at a rate of $13.00 per hour. Other operating costs are listed in the Appendix. Colstrip 4 has an operating cost of $0.04 per KW hour which serves as a sound estimate for this plant. Power will be sold at a rate of $0.044 per KW hour, allowing a profit of $0.004 per KW hour. This money can be applied toward operating costs of the reverse osmosis plant.

The plant will be located on the east rim of the Berkeley Pit as shown in Figure IV. This land can be purchased from Montana Resources at an estimated price of $3,000 per acre.

The possibility of evaporating the brine was examined also. An initial investment of $20.5 million would be necessary for an evaporator plant for this process. While this investment is much less than the $800 million cost of the generating plant, evaporation would not provide a profit. Consequently, there would be an additional yearly cost of $3 million to operate the reverse osmosis plant plus the operating cost of the evaporation plant. The generating plant, however, would not need further investment beyond the initial capital investment. It is estimated that the power generated will not only account for the reverse osmosis operating costs, but may provide up to $90,000 per year to apply toward payment of the plant itself. Hence, the generating plant is the most feasible option.

CONCLUSION

It is evident that the problem of contaminated water rising in the



1. Water From Pit
2. Main Pump
3. Lime Addition
4. Thickener
5. Sludge to Pit
6. Precipitate Inhibitor
7. Reverse Osmosis Modules
8. Water Holding Tank
9. Water for Credit
10. Brine to Coal Plant
11. Water to Coal Plant
12. Boiler
13. Cooling Tower
14. Coal Conveyor
15. Coal Storage
16. Steam
17. Turbines
18. Steam Recycle
19. Generator
20. Transformer
21. Power Station
22. Fly Ash
23. Bag House
24. Scrubber
25. Stack
26. Dust Disposal
27. Lime Storage

FIGURE III PLANT PROCESSES

Berkeley Pit must be solved. This proposal would effectively handle the contaminants in the water and keep the water level down at the same time. Reverse osmosis appears to be the only effective method to purify this amount of water. Cost of this method is offset by the power production in the coal plant. The coal plant also presents a way to treat the harmful contaminants in the water. Thus the feasibility of this solution is evident.

Considerable research still needs to be done to prove how effective the reverse osmosis-electrical generating plant will be in cleaning up the Berkeley Pit. The 800,000 gallons per day of brine produced is only an estimate, and is contingent upon the success of the reverse osmosis plant. Research has to be performed to determine if the membranes will stand up to the conditions associated with this project and if the inhibitor will allow the estimated concentration. These membranes are the controlling factors for the amount of brine produced, which in turn influences the size of the electrical generating plant.

FUTURE WORK

The estimated $800 million is for construction and initial operation of this greenfield plant. Land for the plant site is valued at $3,000 per acre. However, the exact quantity of land needed is not known. Since the plant will be constructed within Butte city limits, special licenses and permits may have to be obtained. The electricity generated will be easily marketable and the clean water from the reverse osmosis plant not used as cooling water for the coal plant can be sold for $0.0001 per gallon.

A major question concerning the plant's future is where the $800 million will come from. Although nothing is definite, one possibility might be allocations from the Superfund.

Environmental factors will be a major concern ahead. Since the plant will be located inside the Butte city limits, Environmental Protection laws as well as the public's concern will play a strict part on all emission standards. This may mean an increase on the control equipment used. What to do with the solid ash is a future topic also. It will contain some metals, but if they can be economically recoverable and utilized is a question that has yet to be answered. If they cannot be recovered, a site must be determined for their disposal.

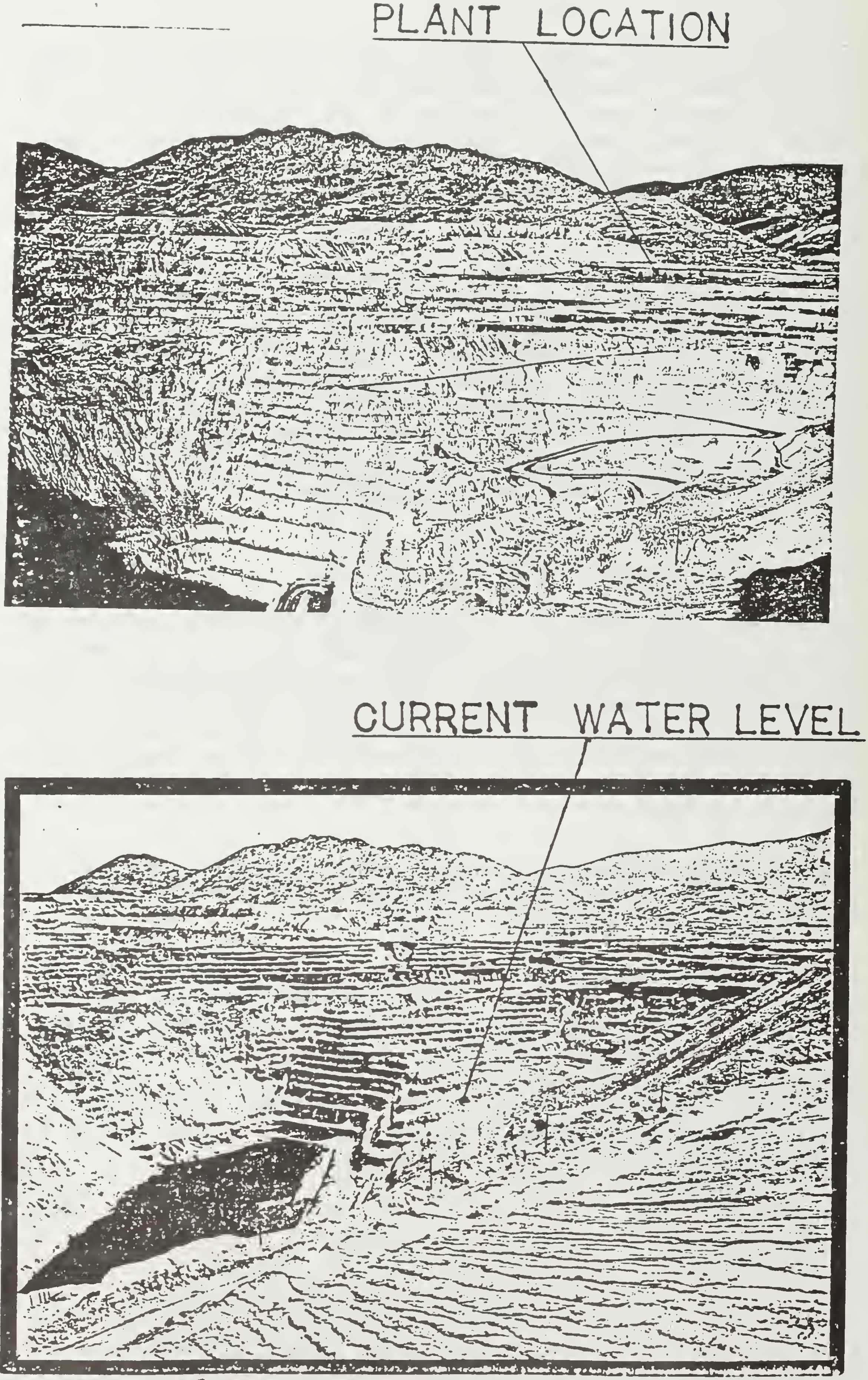


FIGURE IV. Berkeley Pit Views

THEORY

Reverse Osmosis

Osmosis is a process that takes place naturally when a solution's concentration differs between two points. A substance such as water will tend to flow toward a more concentrated solution, so that it can dilute it. When a semi-permeable membrane is used to separate a solution from water, the water continues to flow toward the concentrated side. This flow of water creates an increased pressure on the concentrate side called the osmotic pressure. In a reverse osmosis operation, a pressure is applied on the concentrate side that will exceed the osmotic pressure. This induced pressure will cause pure water to flow away from the concentrate, and through the membrane. This will result in a separation of pure water from the concentrate. Figure V shows the effect of applying an increasing amount of pressure (delta P) to the concentrated solution.

Reverse osmosis technology is currently utilized to desalt or purify water and to concentrate solids in waste effluent. Synthetic, semi-permeable membranes have been developed from polymers to separate solutes from water.

A major side effect of reverse osmosis is concentration polarization. This is the accumulation of solids immediately adjacent to the solute side of the membrane. This causes an increase in the osmotic pressure and reduces the water flux. To overcome this problem, the applied pressure is increased; however, increasing the applied pressure also increases the solute build-up, so there is a maximum flux (flow of water per unit area) for a given membrane. If the applied pressure is increased too much, the concentration of solutes at the membrane surface can become too high, resulting in precipitation of the solids and fouling of the membrane. Experimentation has to be conducted to obtain the optimal membrane and its optimal feed pressure.

Other factors to consider in selecting a membrane are the pH of the solution, hydrophobic substances in the solution and permeability, and the thickness of the membrane. Because the membranes are thin and porous, a support module should be provided. The spiral-wound module is the most applicable in this case. As shown in Figure VI, the feed solution is forced through the membrane which is wrapped around a collector pipe.

The purified water exits through the ends of the pipe. Modules are placed in a pressure vessel where they withstand applied pressures of up to 800 psi and have a 4-7 pH tolerance.

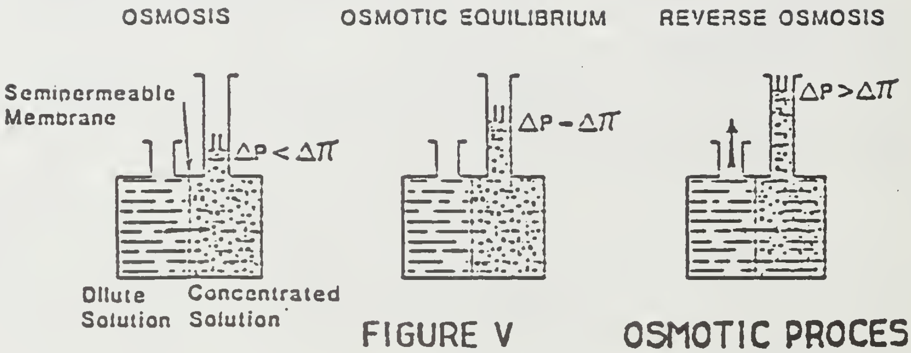


FIGURE V OSMOTIC PROCESSES

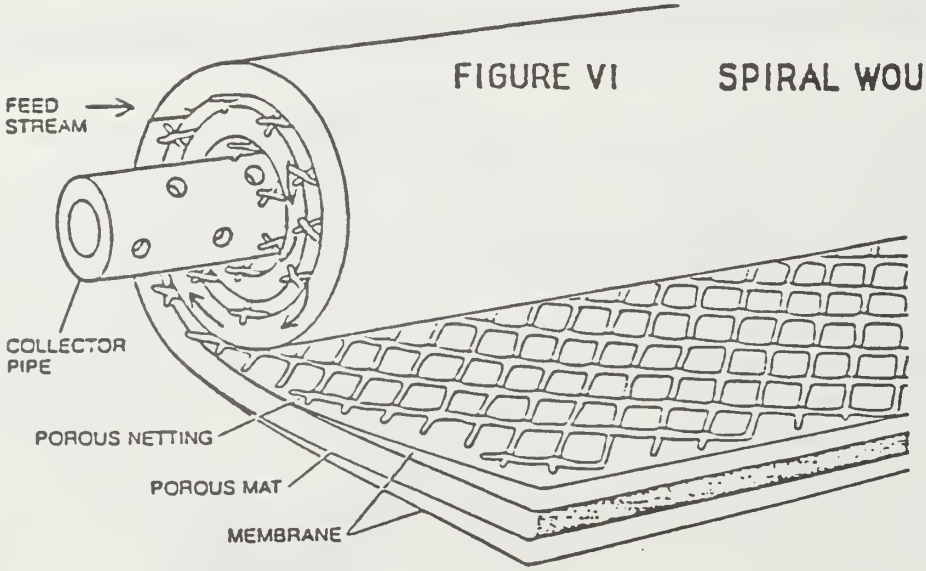


FIGURE VI SPIRAL WOUND MODULE

Electrical Generating Plant

Coal is pulverized to a fine powder, mixed with the brine to form a slurry, and fired to a boiler where it is able to burn and release its energy as heat. Water absorbs this energy as it travels in an intricate path through hollow tubes that make up the sides, top, and bottom of the boiler. Steam, piped from the boiler, strikes the blades of the turbine and revolves the turbine shaft. This spinning shaft is connected to the generator where the magnetized motor turns inside stationary coils of wire. As the magnetic field moves at high speeds throughout the system of wire, electricity is produced. The electricity then goes to transformers outside the plant where the voltage (pressure) is raised and sent by transmission lines to population centers and consumers.

Table 1
Berkeley Pit Samples, October 17, 1986 (mg/L)

	Depth (ft.)	0.5	110	220	330	390	390*	
1.0	Temp (°C)	—	—	—	—	—	—	
	pH	—	—	—	—	—	—	
28	Ca	425	457	450	457	456	455	
31	Mg	149	250	291	310	310	313	
99	Na	59.3	64.7	65.8	66.5	65.4	65.8	
10	K	12.9	19.5	24.3	26.2	26.2	27.8	
99	SiO_2	78.9	104	108	109	111	110	
85	Fe	177	685	918	1,010	1,020	1,060	
94	Mn	64	122	144	154	156	160	
98	Al	91.6	171	192	201	203	209	
.87	Ag	0.019	0.032	0.037	0.043	0.043	0.043	
81	B	0.15	0.25	0.33	0.39	0.40	0.28	
.40	Cd	1.0	1.62	1.74	1.80	1.69	1.70	
.55	Cu	114	196	204	214	213	209	
94	Li	0.16	0.23	0.25	0.27	0.26	0.26	
.74	Mo	0.14	0.21	0.23	0.28	0.25	0.26	
.71	Ni	0.46	0.79	0.91	0.97	0.95	0.99	
97	PO_4 as P	<.1	0.5	0.5	0.5	1.1	1.4	
.62	Sr	0.86	1.03	1.02	1.02	1.00	0.99	
.90	Ti	0.01	0.015	0.022	0.014	0.027	0.062	
.94	V	0.029	0.22	0.27	0.31	0.31	0.31	
.37	Zn	178	375	460	472	477	492	
22	Zr	<.004	0.023	0.049	0.062	0.062	0.065	
.92	As	0.016	0.033	0.041	0.050	0.123	0.188	
72	As (III)	<.001	0.0023	0.005	0.0053	0.0043	0.0047	6.6
.93	Co	0.57	0.94	1.05	1.06	1.07	1.07	
.00	Cr	0.004	0.042	0.050	0.055	0.047	0.048	

*unfiltered sample; all samples acidified with 1/2% nitric acid

REFERENCES CITED

Berg, Dr. Lloyd, Professor of Chemical Engineering, Montana State University, Bozeman, Montana.

Bungay, P.M. et al., Ed. Synthetic Membranes: Science, Engineering, and Applications, H.K. Lonsdale, 1986, pp. 307-342.

Gregor, Harry P. and Charles D., Scientific American, "Synthetic-Membrane Technology," Vol. 239, No. 1, July 1978, pp. 112-128.

Hofacker, Michael A., Senior Technical Engineer, Montana Power Company, Butte, Montana.

Peters, Plant Design and Economics for Chemical Engineers, McGraw Hill, 1958.

Shannon, Robert H., Handbook of Coal-Based Electrical Power Generation, Noyes Publications, 1982, pp. 191-211, 265-273.

Tilman, Ray, Plant Manager, Montana Resources, Butte, Montana.

Titus, Wally, Electrical Engineer, Montana Power Company, Colstrip, Montana.

Workman, Rob, Western Energy, Billings, Montana.

REVERSE OSMOSIS

BERKELEY PIT PROJECT

Submitted To:

Dr. Lloyd Berg

Department of Chemical Engineering

Montana State University

By

Tom Flower
Joel Maroney
Scott Romine
Glenn Stroud

Dr. Lloyd Berg, Chairman, Chemical Engineering Department, Montana State University, has an extensive track record in applying new ideas to difficult engineering problems. With his support two teams of graduate students have suggested some ideas for the water/mineral question in Butte.

ABSTRACT

Highly contaminated, acidic water has been accumulating in the Berkeley Pit in Butte since mining ceased in 1982. If the water level continues to rise, it will eventually contaminate the ground water and cause flooding in the surrounding area. In order to purify enough water to maintain the level in the pit, a reverse osmosis plant is being proposed. The water will be pumped from the pit and then its pH will be adjusted. This pH-adjusted stream will be run to thickeners, followed by treatment by sodium hexametaphosphate. The water will then be split into four feedstreams, filtered, and concentrated in the reverse osmosis process.

The reverse osmosis plant will be capable of processing 8 million gallons of contaminated water per day. It, in turn, will be concentrated 90 percent to produce 7.2 million gallons of pure water and 800,000 gallons of brine per day. The pure water will then be sold or put into Silver Bow Creek to keep pace with the rising water in the pit, while the brine will be returned to the pit or sent to another process.

The figures and specifications for this design are the best possible estimates based upon existing plants. However, due to the nature of the water and current unknowns such as the leaching in the pit, the ultimate success of this plant depends upon future research.

INTRODUCTION

Since mining operations ceased on April 23, 1982, water has been backing up in the mine shafts in Butte. Since this time the water has entered the Berkeley Pit; as of November 4, 1985, the water level in the pit was approximately 425 feet deep (see Figure 1). At this time the water level was approximately 100 feet below the ground water strata. The water level in the pit is currently rising at a rate of 10 inches per month which equates to a flow rate of approximately 7.2 million gallons per day.

The water that is accumulating in the pit contains high concentrations of trace minerals such as copper, aluminum, arsenic, and zinc, as well as other inorganic contaminants such as phosphates and sulphates. Another serious problem with this water is that the pH ranges from 2.5 to 2.65.

If the water level continues to rise, it will eventually make its way into the ground water. This would result in the contamination of nearby streams as well as possibly causing some flooding in areas in and around Butte.

BERKELEY PIT
CROSS SECTION LOOKING WEST

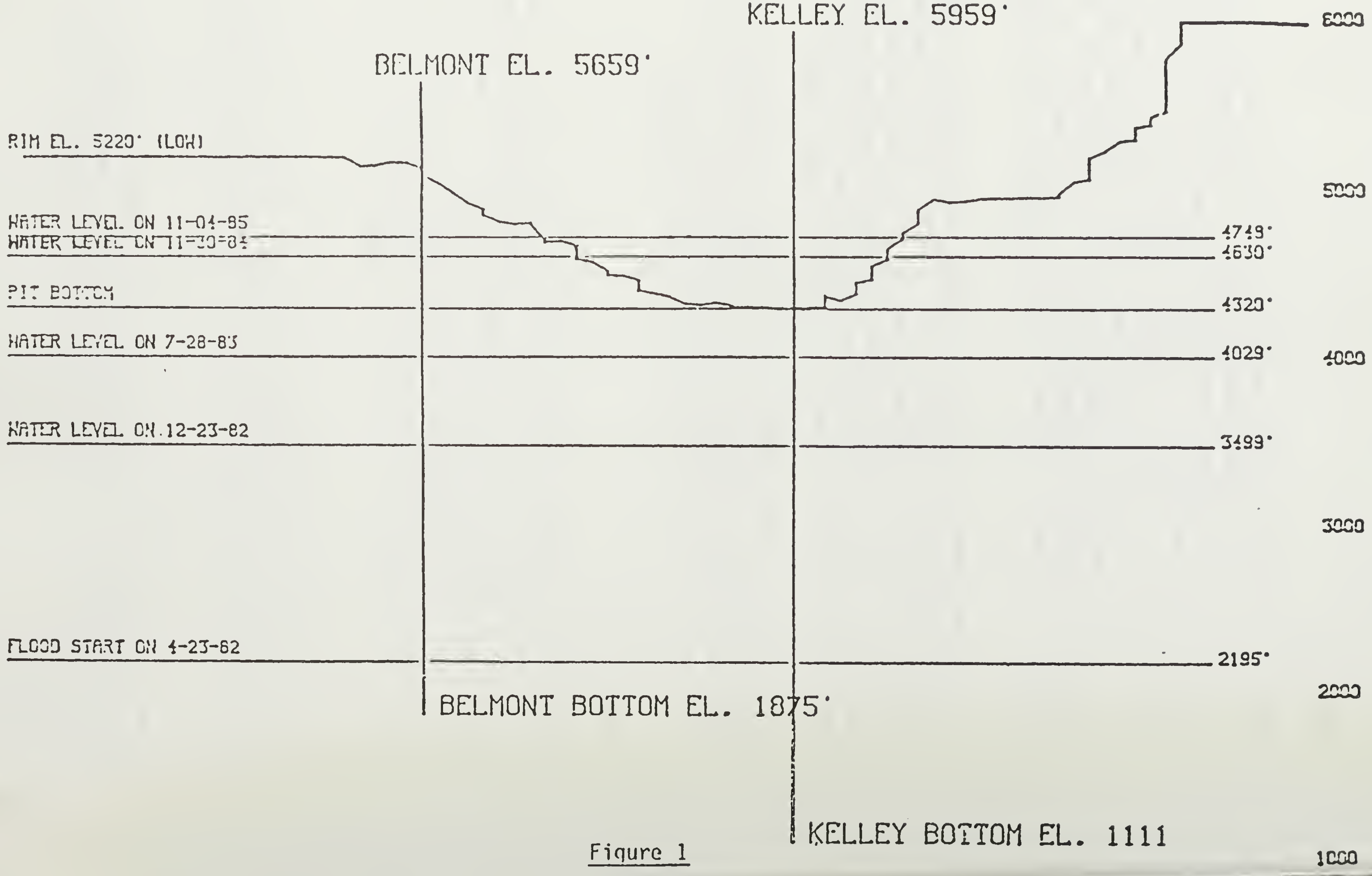


Figure 1

The proposed solution to this problem is to process the water from the Berkeley Pit in a reverse osmosis plant. The proposed plant would process 8.0 million gallons of water per day. The reverse osmosis plant would concentrate the water to ten times its original concentration. This would produce 7.2 million gallons of pure water per day and 800,000 gallons of the concentrated brine per day. The pure water produced from this plant would then be available for drinking water or a variety of other uses.

THEORY

In reverse osmosis, the normal osmotic flow of water down a concentration gradient is reversed by applying a pressure. The normal flow of water across a membrane is from a solution of lower solute concentration to one of higher solute concentration, as in Figure 2. By applying a pressure to the concentrated solution which is just equal to the osmotic pressure difference between the two solutions, water flow ceases and osmotic equilibrium is reached. In reverse osmosis, a pressure is applied to the concentrated solution which is higher than the osmotic pressure; the result is a flow of water from the concentrated to the dilute solution.

As water is removed from a concentrated solution, the osmotic pressure increases. The van't Hoff equation provides a relationship between the osmotic pressure (Pi) and the solute concentration: Pi=CRT, where C is the total number of moles of ions per liter of solution, R is the gas constant, and T is the absolute temperature. This shows that as water is removed, increasing the solute concentration, the osmotic pressure increases. This in turn requires a greater applied pressure (p) for reverse osmosis to occur.

The mass flux of water through reverse osmosis membranes is directly proportional to the "net" pressure, delta p- delta Pi, where delta p and delta Pi are the applied pressure difference and the osmotic pressure difference across the membrane, respectively. Thus, the more the applied pressure exceeds the osmotic pressure, the greater the water flux. Reverse osmosis membranes are also slightly permeable to dissolved solutes. However, the solute molar flux is nearly independent of pressure. The result is that more water passes through the membrane along with a fixed amount of solute when the pressure is increased; the water is thus purer.

RESULTS AND DISCUSSION

The following design features reverse osmosis modules to extract pollutants and produce purified water (see Figure 3).

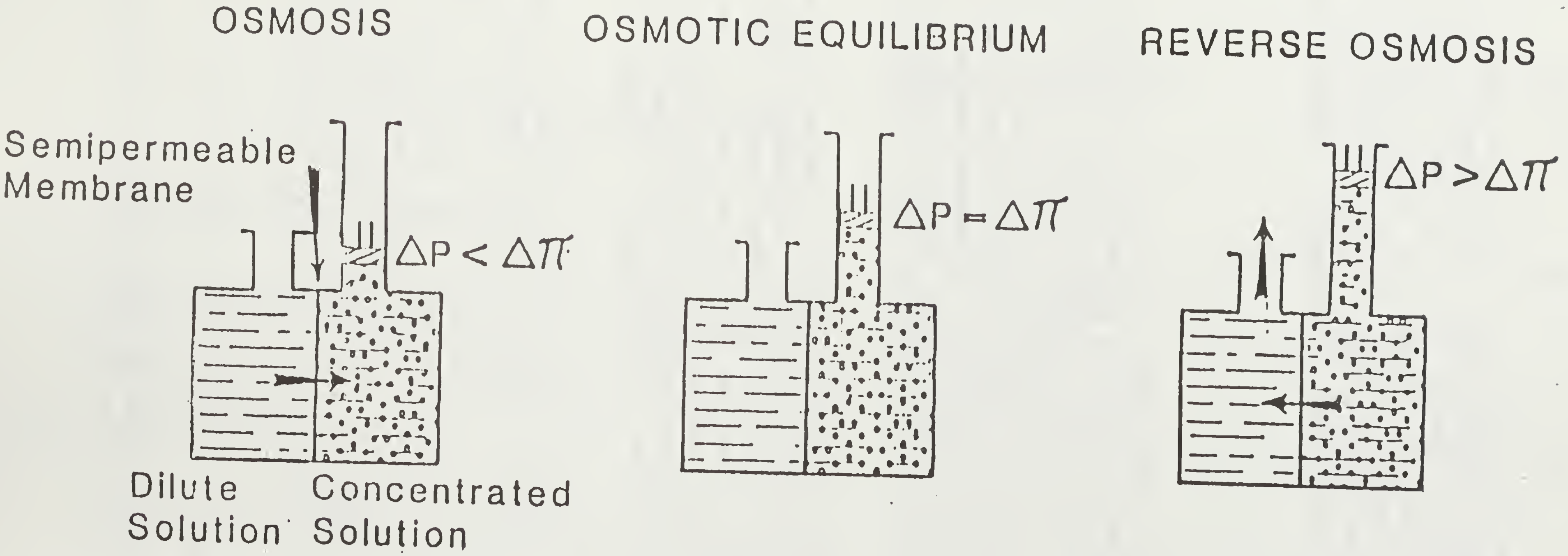
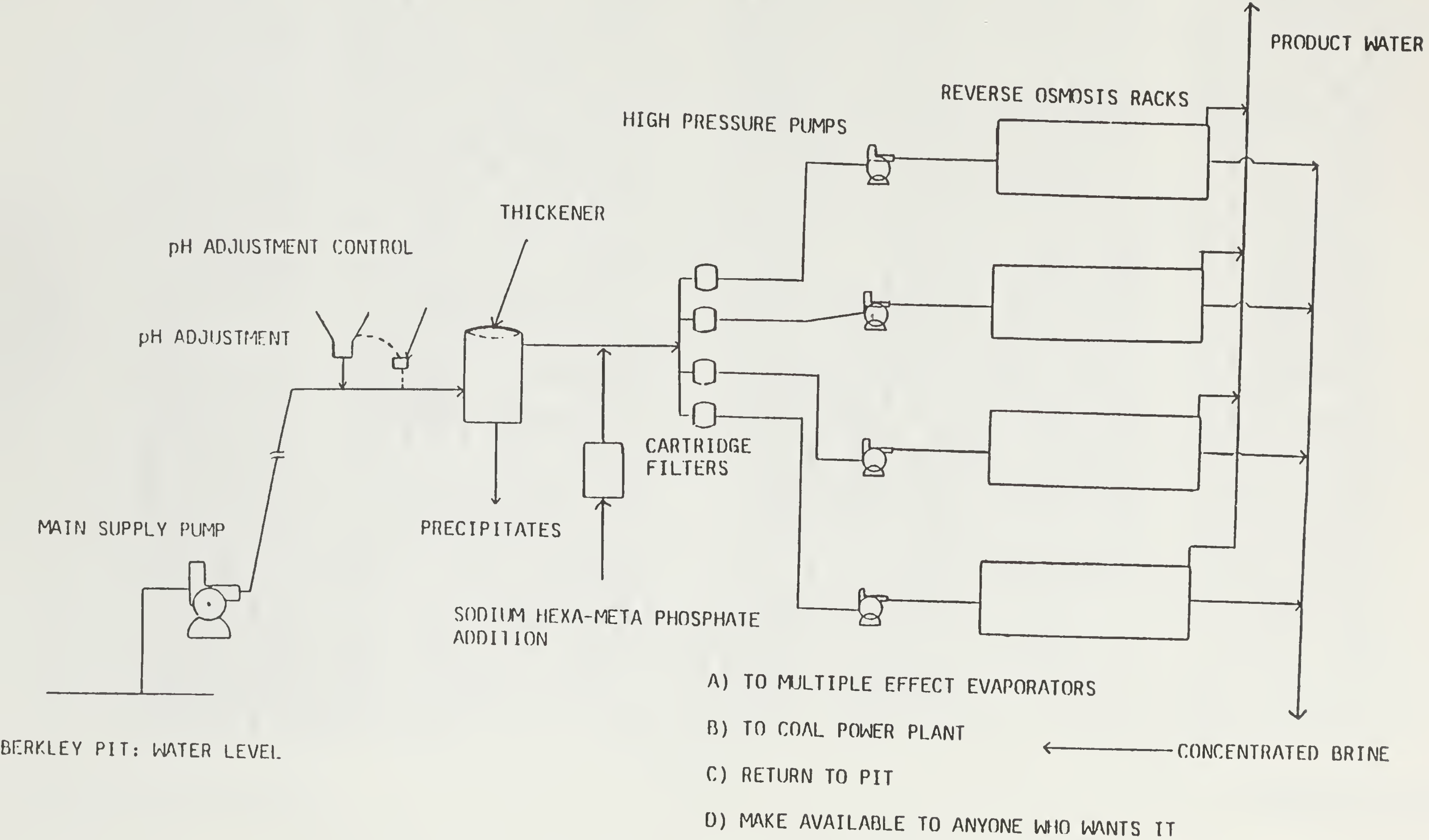


Figure 2. Osmotic Theory

FIGURE 3: REVERSE OSMOSIS FACILITY FLOW DIAGRAM



To start the process the pit water has to be pumped 500 vertical feet and 1,200 horizontal feet to the processing plant. An estimated 5,600 gallons per minute will be processed, or 8.0 million gallons per day. One pumping station will be sited near the water's edge. The pit water will be pumped through a stainless steel pipe that is 20 inches in diameter by an 800 horsepower stainless steel centrifugal pump. Stainless steel is needed for the pump and pipes due to the acidity of the pit water.

Once the pit water has reached the plant, the pH level is adjusted from about 2.5 to 7 by adding a lime slurry. The lime addition is controlled by a twin screw pump. About 3.5 tons of lime will be added per day. A pH monitor will be placed downstream to test the pH level, and a controller will be used to maintain the pH at the desired level.

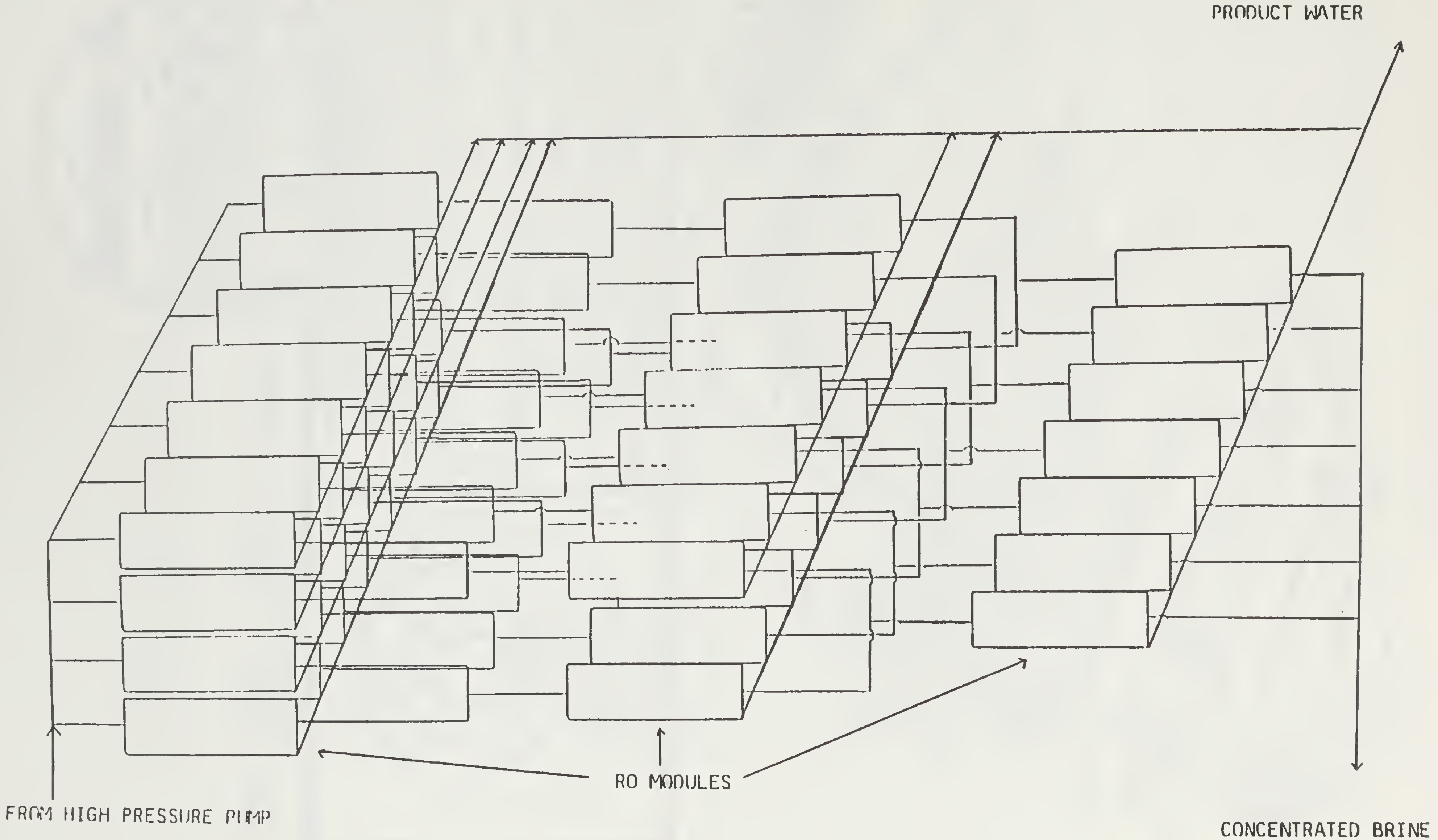
The pH adjustment causes major precipitation of iron and aluminum. These precipitates will be removed in thickeners that are large enough to allow settling time for the precipitators. A rotating arm draws the sludge into the discharge cone at the bottom of the thickener. The sludge is then pumped back to the pit.

A precipitation inhibitor, sodium hexametaphosphate, is added to the process water. The precipitation inhibitor is added to prevent precipitation as the water is concentrated in the reverse osmosis modules. Precipitation must be avoided as it causes fouling in the reverse osmosis membranes.

The process water is split into four lines and run through a filter system. Cartridge filters are used for easy replacement. The filters are necessary to protect the pumps from abrasion and the reverse osmosis modules from fouling. Four high pressure pumps are used to bring the process water pressure up to 400 psi. The high pressure water is piped to four racks of reverse osmosis vessels. Each of the four racks contains seven arrays of reverse osmosis vessels. Each of the seven arrays in turn contains seven vessels which are aligned in a 4:2:1 ratio (see Figure 4). Each vessel has four elements for a total of 784 elements. These elements contain the actual reverse osmosis membranes. The brine out of the last reverse osmosis element will have an exit pressure of 120 psi. The osmotic pressure of the concentrated brine will be 100 psi.

For this plant, spiral wound elements were chosen over hollow tube elements because the spiral wound elements have a larger surface area, thus accommodating a higher flux per unit (see Figure 5). Fluid Systems Magnum spiral wound elements will be used because they have fewer sealing surfaces and distribute the load over the active diameter of the element for improved durability. Brackish water membranes are

FIGURE 4: REVERSE OSMOSIS RACK SHOWING 4-2-1 ARRANGEMENT WITH ACTUAL NUMBER OF VESSELS PER RACK



REVERSE OSMOSIS VESSEL

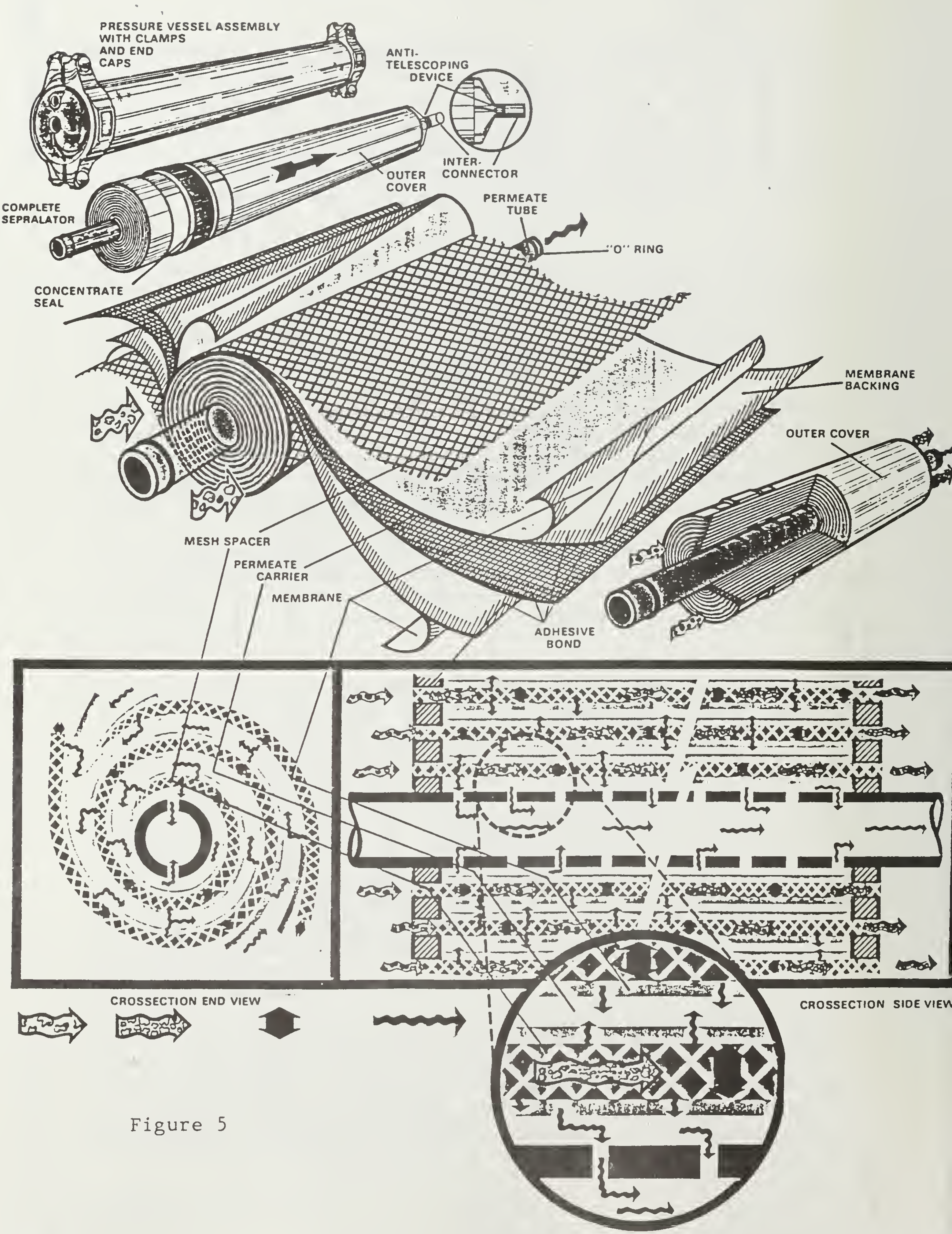


Figure 5

planned for use in the elements; however, actual testing of the water and membranes will determine which membrane material will work best.

During planned operation, 7.2 million gallons of product water will be recovered from the reverse osmosis modules. In addition, 800,000 gallons per day of concentrated brine will be produced. The feed from the pit has a concentration of 0.065 moles per liter; the concentrated brine would have a concentration of 0.65 mol/l, about ten times the concentration of the pit water.

The proposed plant site is just off the Berkeley Pit's eastern rim. Locating close to the pit lowers pumping costs and makes the pit more accessible for analysis. This site should be ten acres and is available at a reasonable cost of $3,000 per acre. Montana Resources is located nearby and is a possible market for the product water. The rim location was chosen over one of the pit's ledges because of safety considerations. The liability risks are too high to locate in the pit's perimeter.

This facility will produce 7.2 million gallons per day of potable water. A possible market for this water is Montana Resources, which would use about 3 million gallons per day. The water may also be used as irrigation water by farmers in the Butte community.

Two other credits may also be taken from this brine. The brine contains relatively large amounts of copper and zinc. The copper has a value of about $2.5 million per year, about the same as the zinc. Due to the low demand for both of these metals, neither is considered as a marketable product of the facility. The demand for copper and aluminum as well as the other metals in the brine currently makes them unattractive for separation and marketing.

Since this plant is a cleanup operation and its products are of little value compared to its costs, plant cost minimization was a key in its design.

An economic analysis of the plant yielded a total grassroots capital investment of about $7.6 million (see Table 1). The bulk of this sum cane from the reverse osmosis plant, which totaled about $7.2 million. This price was derived from a quote by a Universal Oil Products (UOP) representative for a capital investment of $1 per gallon per day of product water, and included the sodium hexametaphosphate injection, cartridge filtration, high pressure pumping system, and the actual reverse osmosis units.

The operating cost of the plant totaled about $2.35 million for the first three years (see Table 2), but increased to about $3.02 million after the third year of operation, when the reverse osmosis membranes

TABLE 1

TOTAL CAPITAL INVESTMENT

Budget Item	Total
Direct Project Expenses:	
Reverse Osmosis Plant	$7,200,000
Stainless Steel Pipe	72,000
Stainless Steel Pump and Motor	50,000
Thickeners	25,000
Direct Labor	54,000
Total Direct Materials and Labor	$7,401,400
Indirect Project Expenses:	
Freight, Insurance, Taxes	$12,000
Construction Overhead	38,000
Contractor Engineering Expenses	22,000
Total Indirect Project Costs	$72,000
Total Direct and Indirect Costs	$7,473,400
Contingency and Fee:	
Contingency	$41,000
Fee	8,200
Total Contingency and Fee	$49,200
Total Plant Capital	$7,522,600
Auxiliary Facilities:	
Land	$30,000
Site Development	28,000
	$58,000
Total Fixed Capital	$7,550,600
Working Capital (1 month supply)	
Sodium Mexametaphosphate	$13,130
Lime	39,300
Filters	5,530
Total Working Capital	$57,960
TOTAL GRASS ROOTS CAPITAL	$7,608,560

TABLE 2

DIRECT MANUFACTURING EXPENSES

Expense Item	Total
Operating Cost per Day:	
Electricity	$3,381.84
Labor	748.80
Supervisory and Clerical	74.88
Equipment Maintenance	564.48
Membrane Cleaning Cost	23.04
Lime	1,311.20
Sodium Hexametaphosphate	437.76
Cartridge Filters	184.32
Total Daily Cost:	$6,726.32
Membrane Replacement	1,900.80
Total Daily Cost After Three Years	$8,627.12
Total Yearly Operating Expense	$2,354,000
Total Yearly Operating Expense After Three Years	$3,019,000
Water Credits per Year	$108,000
Total Yearly Operating Costs	$2,246,000
Total Yearly Operating Costs After Three Years	$2,911,000

require replacement. These values were based on figures from an existing reverse osmosis plant and scaled to appropriate flow rates and current dollars. Presently, the only credit for the plant is the pure water, which will generate about $108,000 per year.

CONCLUSIONS

The use of reverse osmosis for processing contaminated water from mines is a proven method; however, due to the nature of the water in the Berkeley Pit, substantial research will be necessary prior to the construction of this plant. Samples of the solution must be tested to ensure that the sodium hexametaphosphate will prevent the precipitation of solids as the water is concentrated in the reverse osmosis elements. The settling parameters of the solids produced from adjusting the pH must also be determined to accurately design the thickeners.

Because of the ion concentration of this solution, spiral wound elements will be used. While hollow fiber elements are also in widespread use and are less expensive, they foul quite easily. Spiral wound elements also accommodate a higher flux, providing more surface area per element. It will be necessary to actually test these membranes to ensure that they can handle this solution, and perhaps it will be necessary to develop a membrane which is suited for the highly contaminated pit water.

The total capital investment for this plant is $7.5 million and the yearly operating expense is $2.35 million. It is predicted that the reverse osmosis elements will require replacement after three years, and then the yearly operating expense will be $3.02 million. The costs of the reverse osmosis portion of the plant were obtained from Fluid Systems, a division of UOP. This company has extensive experience in designing this type of system and they produce the elements on which this design is based. The operating costs for this plant were based on reported costs from an existing reverse osmosis plant and then scaled up to our design specifications. If uses for the concentrated brine such as recovery of the valuable metals is possible, it will greatly offset the operating expenses for this process and will make the project more feasible.

From the results of future research, the final design and costs of this plant can be determined.

FUTURE OUTLOOK

The proposed reverse facility would solve the problem created by the polluted water rising in the Berkeley Pit. Removing 7.2 million gallons of clean water per day would hold the level of the water constant and keep it from rising to and flowing into the ground water strata. It would also provide a source of clean water for the Butte community. Currently, Montana Resources would be able to use 3.0 million gallons of water per day for their molybdenum concentrating plant. In the future other uses, including drinking water, would be developed.

Initial plans call for recycling the 800,000 gallons of concentrated brine back into the pit. Other options were also considered (see Figure 6).

The first option would use the brine to form a coal slurry to be fed to an electric power plant. The minerals that the water contains would then be deposited on the fly ash from the burning of the coal. This has been research by another group.

The second option considered used multiple-effect evaporators and driers to separate the water from the dissolved solution. This plan was dismissed, since the cost of the evaporators and driers, as well as the operating costs, would be prohibitive.

The third option is just to put the brine back into the pit. While this does not remove the minerals from the pit, it will keep the water from ever reaching the ground water strata and polluting the Butte community's water sources. This ties in with the fourth option, which is to make the brine available to anyone who wants to process it for the minerals it contains. The pit water contains many valuable metals which could be separated and marketed.

The proposed reverse osmosis facility uses state-of-the-art technology and materials which are readily available. Common materials including pumps, thickeners, and chemical treatment comprise the rest of the facility, and are also readily available for commercial use. Land for siting the facility is also available at a reasonable cost, making the reverse osmosis plant an attractive solution for the problem presented by the water rising in the Berkeley Pit.

More research will be necessary for implementing this facility. While the reverse osmosis process is state of the art, the most effective type of membrane for the pit's water will have to be determined by research. Reverse osmosis has never been used on water of this nature, so membranes will have to be tested for durability and effectiveness in separating the dissolved solids from the water before being applied to this problem.

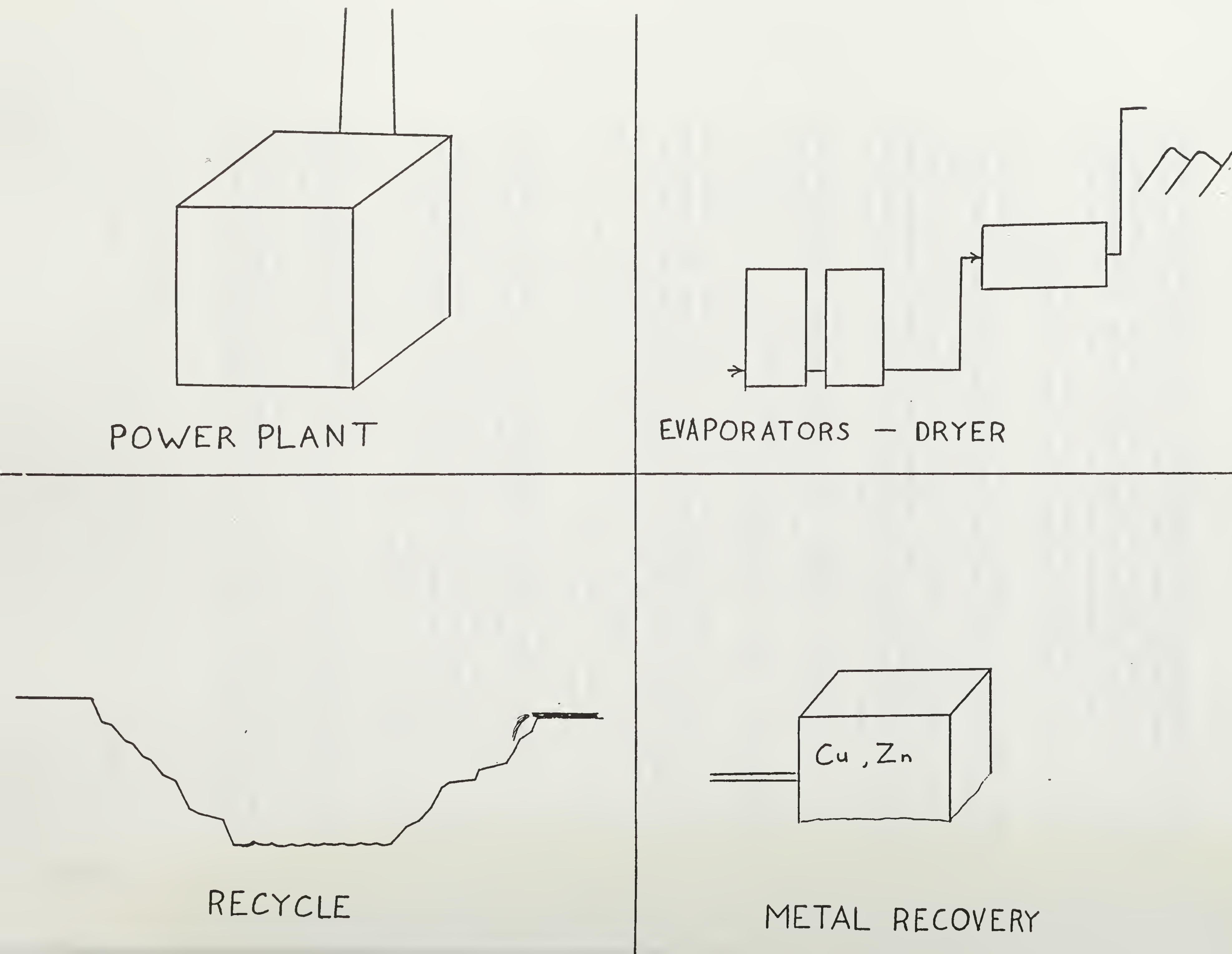


FIGURE 6: OPTIONS FOR BRINE USES

REFERENCES CITED

Lonsdale, H.K., Synthetic Membranes: Science, Engineering and Applications, D. Reidel: Holland, 1986, pp. 309-310.

Osmonics, Customer Literature Brochure.

TENTATIVE RECLAMATION COSTS FOR BERKELEY PIT WATER

By

Paul L. Wichlacz

Idaho National Engineering Laboratory

Dr. Paul Wichlacz, Scientist, Idaho National Engineering Laboratories, has developed a reputation for aggressive innovative thinking, particularly in the field of biotechnology.

Thank you for inviting me to the recent HRI organizational meeting. Both Peter Pryfogle and myself found the meeting most interesting and informative. I think that HRI has some very exciting prospects to pursue. I also think you have managed to bring together the critical people necessary for making something productive happen.

We've done some "quick and dirty" calculations on the value of the metals in the pit (see Table 1). The values given are indicative of total value and do not include refining costs to necessarily realize the value. Processing costs, if processes exist, are likely to overwhelm the value of the metals in the water. Intuitively, processing of 7.2 million gallons of water to recover $295 of silver value is not likely to be cost-effective.

We have also attempted to roughly estimate some of the daily operating costs in an effort to determine the feasibility of mining the water. Two operating costs have been used in our estimates: 1) pumping (electrical) costs; and 2) neutralization costs. We have included pumping costs because we know we have to move the water from the pit. We have used the cost of lime for neutralization of acidity in the water as a rough operating cost for water treatment. Lime neutralization/precipitation is the current method of choice for acid mine water treatment. Assuming that lime treatment is the most cost-effective PAT (presently available technology), it at least represents a reasonable lower limit for processing costs.

Assuming:
- 7.2 mgd water
- Pumping head is 1,000 feet
- 100% pump efficiency
- Electricity cost is $0.06/Kwh
- pH of water is 2.0
- Lime costs $0.17/lb.

Pumping Costs: Daily pumping costs will be equal to

$$\frac{(1000\text{ ft})\ (8.35\text{ lb/gal})\ (5000\text{ gpm})\ (\$0.06/\text{Kwh})\ (24\text{ hrs/day})}{(33{,}000\text{ ft-lb/min HP})\ (1.341\text{ HP/Kw})} = \$1{,}350/\text{day}$$

Lime Costs: To achieve a pH of 7.0 using slaked lime (CaOH2) at stoichiometric equivalency will be equal to:

$$1\text{-Mole Ca(Oh)2} = 40.1 + 2(16.0 + 1.0) = 74.1\text{-grams/Mole}$$

$$74.1\text{-grams/Mole} \times 0.005\text{-Moles/L} \times 3.785\text{L/gal} \times 7.2\text{ mgd} \times$$

$$0.0022\text{-lb/gram} \times \$0.17/\text{lb.} = \$3{,}776/\text{day}$$

Also attached to this report is a partial list of reports addressing metals in the environment and bioconcentration schemes, natural and otherwise. We have these reports on hand, so if you would like to see any of them, let us know and we will send them to you.

Also attached is an EPA Summary by Jennett, et al. which briefly describes a meander system used to remove metals from mine and mill wastes. The entire report is available from NTIS (National Technical Information Service) in Washington, D.C. by calling 208/487-4650.

TABLE 1

TENTATIVE METALS VALUES

Scenario #1: 7.2 MGD = 27.24 MLD (3.785 liters/gallon)

Element	mg/L	Kgr/day	lbs/day	$/lb	Value
Ag	0.043	1.17	3	98.12	$ 295
Cu	209.00	5696.00	12,560	0.63	7,913
Ni	0.99	27.00	60	10.00 ?	600
Zn	492.00	13,408.00	29,560	0.46	13,600
Co	1.07	29.00	65	6.00	390
Al	209.00	5695.00	12,555	0.55	6,905
Mg	313.00	8530.00	18,805	1.48	27,830
Mn	160.00	4360.00	9,615	1.43	13,749
Mo	0.26	7.09	15	3.12	47
Total:					$71,329

Specific Metals:

Ag	$ 295
Cu	7,913
Zn	13,600
Co	390
Mo	47
	$22,245

For total worth of metals dissolved in the pit we can take the total daily production and multiply by the time (in days) that the pit has been filling with water. For example:

> Copper at $7,913, multiplied by 1,771 days (days from April 23, 1982 until end of February 1987) = $14,013,923.

Silver	$295	x	1771	=	$522,445
Zinc	$13,600	x	1771	=	$24,085,600
Cobalt	$390	x	1771	=	$690,690
Molybdenum	$47	x	1771	=	$83,237

Metals

Date of Last Entry: 5/09/86 Entered by: P.A. Pryfogle

Aulio, K. 1983. Heavy Metals in the Green Alga *Cladophora* *glomerata* as Related to Shore Types in the Achipelago Sea, SW Finland. *Marine Pollution Bulletin*, volume 14, number 9, page 347-348.

Austin, A., J. Deniseger, and M.J.R. Clark. 1985. Lake Algal Populations and Physico-Chemical Changes After 14 Years Input of Metallic Mining Wastes. *Water Research*, volume 19, number 3, page 299-308.

Babb, J.M., S.K. Enger, and G.K. Pagenkopf. 1985. Chemical Changes in a Receiving Stream Due to Oxygenation and Dilution of Mine Tailings Seep Waters. *Water, Air, and Soil Pollution*, volume 26, page 219-224.

Baham, J. and G. Sposito. 1983. Chemistry of Water-Soluble, Metal-Complexing Ligands Extracted from an Anaerobically-Digested Sewage Sludge. *Journal of Environmental Quality*, volume 12, number 1, page 96-100.

Bates, S.S., M. Letourneau, A. Tessier, and P.G.C. Campbell. 1983. Variation in Zinc Adsorption and Transport during Growth of *Chlamydomonas variabilis* (Chlorophyceae) in Batch Culture with Daily Addition of Zinc. *Canadian Journal of Fisheries and Aquatic Sciences*, volume 40, number 7, page 895-904.

Bates, S.S., A. Tessier, P.G.C. Campbell, and M. Letourneau. 1985. Zinc-Phosphorus Interactions and Variation in Zinc Accumulation during Growth of *Chlamydomonas* *variabilis* (Chlorophyceae) in Batch Culture. *Canadian Journal of Fisheries and Aquatic Sciences*, volume 42, number 1, page 86-94.

Bauda, P. and Block, J.C. 1985. Cadmium Biosorption and Toxicity to Laboratory-Grown Bacteria. *Environmental Technology Letters*, volume 6, page 445-454.

Borgmann, U. and K.M. Ralph. 1983. Complexation and Toxicity of Copper and the Free Metal Bioassay Technique. *Water Research*, volume 17, number 11, page 1697-1703.

Brierley, Corale L. 1982. Microbiological Mining. *Scientific American*, volume 247, number 2, page 44-53.

Brochiero, E., J. Bonaly, and J.C. Mestre. 1984. Toxic Action of Hexavalent Chromium on *Euglena* *gracilis* Cells Strain Z Grown Under Heterotrophic Conditions. *Archives of Environmental Contamination and Toxicology*, volume 13, page 603-608.

Czuba, M. and D.C. Mortimer. 1983. Effects of Heavy Metals Absorbed from Water on the Laser-Induced Fluorescence in *Elodea* *densa*. *Ecotoxicology and Environmental Safety*, volume 7, page 447-450.

Metals

Daday, A., A.H. Mackerras, and G.D. Smith. 1985. The Effect of Nickel on Hydrogen Metabolism and Nitrogen Fixation in the Cyanobacterium *Anabaena cylindrica*. *Journal of General Microbiology*, volume 131, number 2, page 231-238.

Daniel, G.F. and A.H.L. Chamberlain. 1981. Copper Immobilization in Fouling Diatoms. *Botanica Marina*, volume 24, number 4, page 229-243.

Erdman, J.A. and P.J. Modreski. 1984. Copper and Cobalt in Aquatic Mosses and Stream Sediments from the Idaho Cobalt Belt. *Journal of Geochemical Exploration*, volume 20, page 75-84.

Eskew, D.L., R.M. Welch, and E.E. Cary. 1983. Nickel: An Essential Micronutrient for Legumes and Possibly All Higher Plants. *Science*, volume 222, number 4624, page 621-623.

Fezy, J.S., D.F. Spencer, and R.W. Greene. 1979. The Effect of Nickel on the Growth of the Freshwater Diatom *Navicula pelliculosa*. *Environmental Pollution*, volume 13, page 131-137.

Filip, D.S., T. Peters, V.D. Adams, and E.J. Middlerbrooks. 1979. Residual Heavy Metal Removal by an Algal-Intermittent Sand Filtration System. *Water Research*, volume 13, number 3, page 305-313.

Foster, P. 1976. Concentrations and Concentration Factors of Heavy Metals in Brown Algae. *Environmental Pollution*, volume 10, page 45-53.

Franz, G.N. 1977. Effects of Coal Combustion and Gasification Process Contaminants on the Neuromuscular System. DOE/METC/8087-T1, 23 pages.

Freeman, M.C. 1985. The Reduction of Arsenate to Arsenite by an *Anabaena*-Bacteria Assemblage Isolated from the Waikato River. *New Zealand Journal of Marine and Freshwater Research*, volume 19, page 277-282.

Fujiyama, T. and M. Maeda. 1977. Content and Uptake of Trace Metals in Benthic Algae, *Enteromorpha* and *Porphyra*. I. Measurement and Variation of Trace Metal Content of *Porphyra* Grown in Natural Environment. *Journal of Faculty of Fisheries and Animal Husbandry*, volume 16, page 23-32.

Gosset, T., J.-L. Trancart, and D.R. Thevenot. 1986. Batch Metal Removal by Peat: kinetics and Thermodynamics. *Water Research*, volume 20, number 1, page 21-26.

Guy, R.D. and A.R. Kean. 1980. Algae as a Chemical Speciation Monitor - I. A Comparison of Algal Growth and Computer Calculated Speciation. *Water Research*, volume 14, number 7, page 891-899.

Hardie, L.P., D.L. Balkwill, and S.E. Stevens, Jr. 1983. Effects of Iron Starvation on the Physiology of the Cyanobacterium *Agmenellum quadruplicatum*. *Applied and Environmental Microbiology*, volume 45, number 3, page 999-1006.

Metals

Hardy, J.K. and N.B. Raber. 1985. Zinc Uptake by the Water Hyacinth: Effects of Solution Factors. *Chemoshpere*, volume 14, number 9, page 1155-1166.

Hart, B.A., P.E. Bertram, and B.D. Scaife. 1979. Cadmium Transport by *Chlorella pyrenoidosa*. *Environmental Research*, volume 18, number 2, page 327-335.

Hassett, J.M., J.C. Jennett, and J.E. Smith. 1981. Microplate Technique for Determining Accumulation of Metals by Algae. *Applied and Environmental Microbiology*, volume 41, number 5, page 1097-1106.

Hatch, R.T. and A. Menawat. 1978. Biological Removal and Recovery of Trace Heavy Metals. *Biotechnology and Bioengineering Symposium*, number 8, page 191-203.

Higham, D.P., P.J. Sadler, and M.D. Scawen. 1984. Cadmium-Resistant *Pseudomonas putida* Synthesizes Novel Cadmium Proteins. *Science*, volume 225, page 1043-1046.

Higham, D.P., P.J. Sadler, and M.D. Scawen. 1985. Cadmium Resistance in *Pseudomonas putida*: Growth and Uptake of Cadmium. *Journal of General Microbiology*, volume 131, part 10, page 2539-2544.

Horitsu, H., S. Futo, K. Ozawa, and K. Kawai. 1983. Comparison of Characteristics of Hexavalent Chromium-Tolerant Bacterium, *Pseudomonas ambigua* G-1, and its Hexavalent Chromium-Sensitive Mutant. *Agricultural and Biological Chemistry*, volume 47, number 12, page 2907-2908.

Hornor, S.G. and B.A. Hilt. 1985. Distribution of Zinc-Tolerant Bacteria in Stream Sediments. *Hydrobiologia*, volume 128, page 155-160.

Horner, Sally G. 1983. Microbial Leaching of Zinc Concentrate in Fresh-Water Microcosms: Comparison Between Aerobic and Oxygen-Limited Conditions. *Geomicrobiology Journal*, volume 3, number 4, page 359-371.

Hsieh, K.M., L.W. Lion, and M.L. Shuler. 1985. Bioreactor for the Study of Defined Interactions of Toxic Metals and Biofilms. *Applied and Environmental Microbiology*, volume 50, number 5, page 1155-1161.

Imber, B.E. and M.G. Robinson. 1983. Complexation of Zinc by Exudates of *Thalassiosira fluviatilis* Grown in Culture. *Marine Chemistry*, volume 14, page 31-41.

Jenne, E.A. and S.N. Luoma. ____. Forms of Trace Elements in Soils, Sediments, and Associated Waters. An Overview of Their Determination and Biological Availability. **

Jennett, J.C. and B.G. Wixon. 1972. Problems in Lead Mining Waste Control. *Journal Water Pollution Control Federation*, volume 44, number 11, page 2103-2110.

Metals

Johnson, G.D., A.W. McIntosh, and G.J. Atchison. ****. The Use of Periphyton as a Monitor of Trace Metals in Two Contaminated Indiana Lakes. *Bulletin of Environmental Contamination and Toxicology*, volume 19, number 6, page 733-740.

Kantin, Roger. 1983. Chemical Speciation of Antimony in Marine Algae. *Limnology and Oceanography*, volume 28, number 1, page 165-168.

Khummongkol, D., G.S. Canterford, and C. Fryer. 1982. Accumulation of Heavy Metals in Unicellular Algae. *Biotechnology and Bioengineering*, volume 24, page 2643-2660.

Klotz, R.L. 1981. Algal Response to Copper Under Riverine Conditions. *Environmental Pollution*, Series A, volume 24, page 1-19.

Lawson, P.S., R.M. Sterritt, and J.N. Lester. 1984. Factors Affecting the Removal of Metals During Activated Sludge Wastewater Treatment II. The Role of Mixed Liquor Biomass. *Archives of Environmental Contamination and Toxicology*, volume 13, page 391-402.

Leeper, S.A. and J.H. Wolfram. 1985. Biologically-Assisted Minerals Processing: Metallothionein Status Report: February 1985. *EG&G Idaho, Inc. Internal Technical Report*, Idaho Falls, Idaho, number SE-S-85-001, 48 pages.

Lewandowski, Zbigniew. 1985. Denitrification by Packed Bed Reactors in the Presence of Chromium (VI): Resistance to Inhibition. *Water Research*, volume 19, number 5, page 589-596.

Lewin, Roger. 1984. How Microorganisms Transport Iron. *Science*, volume 225, number 4660, page 401-402.

Lipstein, B. and S. Hurwitz. 1982. The Effect of Aluminum on the Phosphorus Availability in Algae-Containing Diets. *Poultry Science*, volume 61, page 951-954.

Lodenius, M. and A. Seppanen. 1982. Hair Mercury Contents and Fish Eating Habits of People Living Near a Finnish Man-Made Lake. *Chemosphere*, volume 11, number 8, page 755-759.

Lodenius, M., A. Seppanen, and M. Herranen. 1983. Accumulation of Mercury In Fish and Man from Reservoirs in Northern Finland. *Water, Air, and Soil Pollution*, volume 19, page 237-246.

Lundgren, D.G. and E.E. Malouf. 1983. Microbial Extraction and Concentration of Metals. In: *Advances in Biotechnological Processes 1*, published by Alan R. Liss, Inc., New York, New York, page 223-249.

Luong, H.V., J.F. Braddock, and E.J. Brown. 1985. Microbial Leaching of Arsenic from Low-Sulfide Gold Mine Material. *Geomicrobiology Journal*, volume 4, number 1, page 73-86.

Metals

Maeda, M. and T. Fujiyama. 1977. Content and Uptake of Trace Metals in Benthic Algae, *Enteromorpha* and *Porphyra*. II. Studies on the Algae Cultured in Sea Water Supplemented with Various Metals. *Journal Faculty Fisheries and Husbandry*, volume 16, page 33-44.

Maeda, S., S. Nakashima, T. Takeshita, and S. Higashi. 1985. Bioaccumulation of Arsenic by Freshwater Algae and the Application to the Removal of Inorganic Arsenic from an Aqueous Phase. Part II. By *Chlorella vulgaris* Isolated from Arsenic-Polluted Environment. *Separation Science and Technology*, volume 20, number 2&3, page 153-161.

Makar, H.V., D.M. Soboroff, and F.J. Palumbo. 1982. Recovery of Metals and Minerals from Selected Processing Wastes. *Resources and Conservation*, volume 9, page 179-190.

Marshall, Eliot. 1985. Selenium Poisons Refuge, California Politics. *Science*, volume 229, page 144-146.

Marshall, J.S., J.I. Parker, D.L. Mellinger, and S.G. Lawrence. 1981. An *in situ* Study of Cadmium and Mercury Stress in the Plankton Community of Lake 382, Experimental Lakes Area, Northwestern Ontario. *Canadian Journal of Fisheries and Aquatic Sciences*, volume 38, number 10, page 1209-1214.

McEntee, J.D., S.F. Minney, and A.V. Quirk. 1983. Adsorption of Cadmium by a Cadmium-Resistant Organism Isolated from Sewage Sludge. *Progress in Biohydrometallurgy*, page 617-626.

Metha, A.P. and L.E. Murr. 1982. Kinetic Study of Sulfide Leaching by Galvanic Interaction between Chalcopyrite, Pyrite, and Sphalerite in the Presence of *T. ferrooxidans* (30oC) and a Thermophilic Microorganism (55oC). *Biotechnology and Bioengineering*, volume 24, page 919-940.

Mierle, G. and P.M. Stokes. 1976. Heavy Metal Tolerance and Metal Accumulation by Planktonic Algae. *Proceedings of the University of Missouri Annual Conference on Trace Substances and Environmental Health*, number 10, page 113-122.

Minzoni, F. 1984. Effects of Aluminium on Different Forms of Phosphorus and Freshwater Plankton. *Environmental Technology Letters*, volume 5, page 425-432.

Moore, James W. 1981. Epipelic Algal Communities in a Eutrophic Northern Lake Contaminated with Mine Wastes. *Water Research*, volume 15, page 97-105.

Morris, A.W. 1971. Trace Metal Variations in Sea Water of the Menai Straits Caused by a Bloom of *Phaeocystis*. *Nature*, volume 233, number 5319, page 427-428.

Metals

Muller, K.W. and H.-D. Payer. 1980. The Influence of Zinc and Light Conditions on the Cadmium-Repressed Growth of the Green Alga *Coelastrum proboscideum*. *Physiologia Plantarum*, volume 50, number 3, page 265-268.

Newman, M.C., J.J. Alberts, and V.A. Greenhut. 1985. Geochemical Factors Complicating the Use of *Aufwuchs* to Monitor Bioaccumulation of Arsenic, Cadmium, Chromium, Copper, and Zinc. *Water Research*, volume 19, number 9, page 1157-1165.

Norris, A.R., R. Kumar, E. Buncel, and A.L. Beauchamp. 1984. Metal Ion-Biomolecule Interactions. V. Synthesis and Spectroscopic Properties of Methylmercury (II) and Mercury (II) Complexes of Theophylline. *Journal of Inorganic Biochemistry*, volume 21, page 277-286.

Norris, A.R., R. Kumar, and E. Buncel. 1984. Metal Ion-Biomolecule Interactions. VIII. Methylmercury (II) Complexes of 8-Thioguanosine. Synthesis and Spectroscopic Investigations. *Journal of Inorganic Biochemistry*, volume 22, page 11-20.

Norris, P.R. and D.P. Kelly. 1978. Accumulation of Metals by Bacteria and Yeasts. In: *Developments in Industrial Microbiology*, volume 20, chapter 27, page 299-308.

Nuzzi, Robert. 1972. Toxicity of Mercury to Phytoplankton. *Nature*, volume 237, number 5349, page 38-40.

Oliveira, L. and N.J. Antia. 1984. Evidence of Nickel Ion Requirement for Autotrophic Growth of a Marine Diatom with Urea Serving as Nitrogen Source. *British Phycological Journal*, volume 19, page 125-134.

Pakrasi, H.B., A. Goldenberg, and L.A. Sherman. 1985. Membrane Development in the Cyanobacterium, *Anacystis nidulans*, during Recovery from Iron Starvation. *Plant Physiology*, volume 79, page 290-295.

Petersen, Richard. 1982. Influence of Copper and Zinc on the Growth of a Freshwater Alga, *Scenedesmus quadricauda*: The Significance of Chemical Speciation. *Environmental Science and Technology*, volume 16, number 8, page 443-447.

Pettersson, A. L. Hallbom, and B. Bergman. 1985. Physiological and Structural Responses of the Cyanobacterium *Anabaena cylindrica* to Aluminium. *Physiologia Plantarum*, volume 63, page 153-158.

Rao, V.N.R. and S.K. Subramanian. 1982. Metal Toxicity Tests on Growth of Some Diatoms. *Acta Botanica Indica*, volume 10, page 274-281.

Remacle, J., C. Houba, and J. Ninane. 1982. Cadmium Fate in Bacterial Microcosms. *Water, Air, and Soil Pollution*, volume 18, page 455-465.

Remacle, J. and C. Houba. 1983. The Removal of Heavy Metals from Industrial Effluents in a Biological Fluidised Bed. *Environmental Technology Letters*, volume 4, page 53-58.

Metals

Rowand, A. 1985. Trace Metals Leave More Than Trace Effects. *Park Science*, volume 5, number 3, page 373.

Schecher, W.D. and C.T. Driscoll. 1985. Interactions of Copper and Lead with *Nostoc muscorum*. *Water, Air, and Soil Pollution*, volume 24, page 85-101.

Schelske, Claire L. 1962. Iron, Organic Matter, and Other Factors Limiting Primary Productivity in a Marl Lake. *Science*, volume 136, number 3510, page 45-46.

Schottel, J., A. Mandal, D. Clark, S. Silver, and R.W. Hedges. 1974. Volatilisation of Mercury and Organomercurials Determined by Inducible R-Factor Systems in Enteric Bacteria. *Nature*, volume 251, number 5473, page 335-337.

Stary, J., B. Havlik, K. Kratzer, J. Prasilova, and J. Hanusova. 1983. Cumulation of Zinc, Cadmium, and Mercury on the Alga *Scenedesmus obliquus*. *Acta Hydrochimica et Hydrobiologica*, volume 11, number 4, page 401-409.

Stauber, J.L. and T.M. Florence. 1985. The Influence of Iron on Copper Toxicity to the Marine Diatom, *Nitzschia closterium* (Ehrenberg) W. Smith. *Aquatic Toxicology*, volume 6, page 297-305.

Stokes, P.M., T.C. Hutchinson, and K. Krauter. 1973. Heavy-Metal Tolerance in Algae Isolated from Contaminated Lakes Near Sudbury, Ontario. *Canadian Journal of Botany*, volume 51, number 11, page 2155-2168.

Strandberg, G.W., S.E. Shumate, II, and J.R. Parrott, Jr. 1981. Microbial Cells as Biosorbents for Heavy Metals: Accumulation of Uranium by *Saccharomyces cerevisiae* and *Pseudomonas aeruginosa*. *Applied and Environmental Microbiology*, volume 41, number 1, page 237-245.

Sunda, W.G. and S.A. Huntsman. 1983. Effect of Competitive Interactions Between Manganese and Copper on Cellular Manganese and Growth in Estuarine and Oceanic Species of the Diatom *Thalassiosira*. *Limnology and Oceanography*, volume 28, number 5, page 924-934.

Tare, V., S.B. Karra, and C.N. Haas. 1984. Kinetics of Metal Removal by Chelating Resin from a Complex Synthetic Wastewater. *Water, Air, and Soil Pollution*, volume 22, page 429-439.

Telitchenko, M.M., G.V. Tsytsarin, and Y.L. Shirokova. ______ Trace Elements and Algal "Bloom". ______________________________, volume 6, number 6, page 1-6.

Thomas, W.H., J.T. Hollibaugh, and D.L.R. Seibert. 1980. Effects of Heavy Metals on the Morphology of Some Marine Phytoplankton. *Phycologia*, volume 19, number 3, page 202-209.

Metals

Torma, Arpad E. 1983. Biotechnology Applied to Mining of Metals. *Biotechnology Advances*, volume 1, page 73-80.

Trollope, D.R. and B. Evans. 1976. Concentrations of Copper, Iron, Lead, Nickel, and Zinc in Freshwater Algal Blooms. *Environmental Pollution*, volume 11, number 2, page 109-116.

Wavare, R.A. and P. Mohanty. 1982. Aluminium Stimulation of Photoelectron Transport in Spheroplasts of Cyanobacterium *Synechococcus cedrorum*. *Photobiochemistry and Photobiophysics*, volume 3, page 327-335.

Wavare, R.A., B. Subbalakshmi, and P Mohanty. 1983. Effect of Al3+ on Electron Transport Catalysed by Photosystem I & II of Photosynthesis in Cyanobacterium *Synechococcus* Spheroplasts & Beet-spinach Chloroplasts. *Indian Journal of Biochemistry & Biophysics*, volume 20, page 301-303.

Wells, M.L., N.G. Zorkin, and A.G. Lewis. 1983. The Role of Colloid Chemistry in Providing a Source of Iron to Phytoplankton. *Journal of Marine Research*, volume 41, page 731-746.

Westbroek, P., E.W. DeJong, P. Van der Wal, A.H. Borman, J.P.M. DeVrind, D. Kok, W.C. DeBruijn, and S.B. Parker. 1984. Mechanism of Calcification in the Marine Alga *Emiliania huxleyi*. *Philosophical Transactions of the Royal Society of London, Series B*, volume 304, page 435-444.

Whitton, B.A. 1971. Toxicity of Heavy Metals to Freshwater Algae: A Review. *Phykos*, volume 9, number 2, page 116-125.

Whitton, B.A. 1984. Algae as Monitors of Heavy Metals in Freshwaters. In: *Algae as Ecological Indicators*, edited by L.E. Shubert, published by Academic Press, New York, New York, chapter 9, page 257-280.

Wichlacz, P.L. and R.F. Unz. 1981. Acidophilic, Heterotrophic Bacteria of Acidic Mine Waters. *Applied and Environmental Microbiology*, volume 41, number 5, page 1254-1261.

Winger, P.V., C. Sieckman, T.W. May, and W.W. Johnson. 1984. Residues of Organochlorine Insecticides, Polychlorinated Biphenyls, and Heavy Metals in Biota from Apalachicola River, Florida, 1978. *Journal of the Association of Official Analytical Chemists*, volume 67, number 2, page 325-333.

Wollast, Roland. 1982. Methodology of Research in Micropollutants - Heavy Metals. *Water, Science, and Technology*, volume 14, page 107-123.

Wong, M.H. and F.Y. Tam. 1984. Sewage Sludge for Cultivating Freshwater Algae and the Fate of Heavy Metals at Higher Trophic Organisms. II. Heavy Metal Contents of *Chlorella pyrenoidosa* Cultivated in Various Extracts. *Archiv fur Hydrobiologie*, volume 100, number 2, page 207-218.

Wu, J.T. and H. Lorenzen. 1984. Effect of Copper on Photosynthesis in Synchronous *Chlorella* Cells. *Botanical Bulletin of Academia Sinica*, volume 25, page 125-132.

Metals

Wurtsbaugh, W.A. and A.J. Horne. 1982. Effects of Copper on Nitrogen Fixation and Growth of Blue-Green Algae in Natural Plankton Associations. *Canadian Journal of Fisheries and Aquatic Sciences*, volume 39, number 12, page 1636-1641.

Wurtsbaugh, W.A. and A.J. Horne. 1983. Iron in Eutrophic Clear Lake, California: Its Importance for Algal Nitrogen Fixation and Growth. *Canadian Journal of Fisheries and Aquatic Sciences*, volume 40, number 9, page 1419-1429.

Xiankong, Z., F.R. Tabita, and C. van Baalen. 1984. Nickel Control of Hydrogen Production and Uptake in *Anabaena* spp. Strains CA and 1F. *Journal of General Microbiology*, volume 130, part 7, page 1815-1818.

Yan, N.D. and W. Geiling. 1985. Elevated Planktonic Rotifer Biomass in Acidified Metal-Contaminated Lakes Near Sudbury, Ontario. *Hydrobiologia*, volume 120, 199-205.

Young, D.R. and D.V. Ellis. 1982. A Note on Trace Metal Bioaccumulation and Biomagnification in Near-Shore Marine Food Webs. In: *Marine Tailings Disposal*, edited by D.V. Ellis, published by Ann Arbor Science, Ann Arbor, Michigan, chapter 4, page 133-138.

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-82-100 Mar. 1983

Project Summary

Factors Influencing Metal Accumulation by Algae

J. Charles Jennett, J. E. Smith, and J. M. Hassett

Shallow beds of algae (algal meanders) have proved to be highly effective at removing heavy metals and organometallics from lead-zinc mine and mill wastes. A laboratory-scale research program was initiated to determine conditions under which algae were most effective at concentrating significant quantities of As, Cd, Cu, Hg, Ni, Pb, or An, for the purpose of potential application of the meander technology to new types of wastewater-metal problems.

Studies were performed on 20 species of algae to determine interactions of experimental variables affecting metal adsorption, species and strains of algae, type, form, and concentrations of metal, pH, culture age, micronutrient composition of culture medium, exposure to metal, and light intensity and exposure period. These numerous variables were studied by means of a rapid analytical technique, the Titertek™* supernatant collection system, to determine the adsorption of metal radionuclides.

Metal removal was observed to be fast (three hours), young growing cultures were seen to be most effective, and concentration factors > 1 x 10^4 were observed. The pH had little effect on accumulation of metals except lead. Heavy metals could be stripped from algal mats with 0.01 M EDTA or 0.1 N HNO_3. Ca and Mg were not effective competitors for the binding sites of Hg, Pb, and Cd. Neither Zn nor As was bound significantly at any pH. Experimental and literature data indicate that algae remove certain metals economically from a variety of waters and that the meander system can be used to recover these metals for processing.

This report is submitted in fulfillment of Grant No. R804734 by Syracuse University under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period from September 13, 1976 through January 1, 1979 and work was completed as of June 30, 1979.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Effluents from secondary lead smelters are a major source of heavy metals in the aquatic environment. These effluents are frequently low in pH and contain a wide range of heavy metals. The largest single heavy metal constituent is, of course, lead. Relatively large amounts of zinc, cadmium, arsenic, copper, and other toxic cations may also be found, along with a wide variety of anions often associated with these metals (chloride, sulfate, nitrate and chromate for example). Lead smelter effluents also contain toxic trace organics generated when batteries and other materials are crushed, and the heavy metals are removed from their plastic encasements. The fact that heavy metals are dangerous in the aquatic environment has been well documented in the literature.

To protect the environment, the discharge of heavy metals must be minimized. One approach is to apply the type of algal-meander treatment system cur-

---

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency.

rently in use for treating mine and mine-mill wastes at one site in the new lead-belt region in southeast Missouri—the world's largest lead mining region. A detailed laboratory study of the factors influencing heavy metal accumulation by algae is the subject of this investigation and an attempt has been made to evaluate the feasibility of using algal meanders to remove a variety of heavy metals.

Description of the Meander Process

In the Missouri algal-meander system, mine and mill wastes were treated in a standard tailings pond followed by a series of shallow meanders in which the growth of algae is encouraged. These algae grow, utilize the waste millings reagents and trap heavy metals, both particulate and dissolved, on their surface. When the algae mat breaks loose, it is then trapped in a settling pond at the end of the meander system. The pond is equipped with baffled weirs which prevent algal overflow into the receiving stream. Based on total heavy metals removed, the system is more than 99-percent effective. Dissolved heavy metals are also removed to levels well below U.S. Public Health Service drinking water standards. Past work has shown also that lead in its highly soluble acetate form is removed effectively by the algae.

To date, the algal-meander system has been used to treat only one waste, a combined lead-zinc mine and mill waste in the new lead-belt mining region. Since 1971, this region has been the site of a large interdisciplinary investigation, supported by the National Science Foundation, of environmental pollution by lead and other heavy metals. It was confirmed in 1974 that below the AMAX-Homestake Lead Tollers, Inc., mining mills, severe stream degradation and heavy metal buildup was occurring. The meandering system was built to a full operating scale and as a result the stream was returned to essentially pre-mining conditions. The history of this treatment system and the quality of the water in receiving streams has been well documented for lead and zinc. This technology, however, has not been applied to wastes containing other toxic metals. This has been largely due to the lack of information on the system's range of application and the newness of the technology. The ability of algae to concentrate heavy metals from their aqueous environment has been reported by radioecologists examining debris from nuclear tests, chemical geologists attemoting to explain low-grade deposits of metal, and ecologists concerned with the self-purification of streams below mining operations. While these observations are clearly valuable, a more detailed knowledge of the interaction between algae and heavy metals could aid in understanding these processes. A systematic study of these interactions has been difficult because a wide range of variables affects metal accumulation by algae. These variables include the length of the exposure period, the type of metal, oxidation states, pH, salinity, and presence of organic pollutants. To understand the factors influencing metal accumulation by algae in the meander system, laboratory studies were initiated with pure cultures of representative species from other laboratories and from the algal culture collection at the University of Texas.

Conclusions

The ability of representative algae to concentrate large quantities of specific heavy metals was demonstrated by adapting the Titertek™ supernatant collection system (Flow Laboratories, Rockville, Maryland) for assaying radionuclides of heavy metals. This technique permitted the simultaneous study of several factors affecting heavy metal accumulation and provided a sufficient number of replicates for statistical analysis. Algal-metal combinations used in batch studies are presented in Table 1.

The removal and concentration of heavy metals from their aqueous environment by algae was first studied in detail in the 1950s and 1960s as part of the problem of the release of nuclear debris from weapons testing, and from reactor cooling water effluent. Scientists took advantage of the released isotopes, as well as newly developed analytical techniques, to study pathways of various elements in the environment. One early result of this work was the observation that certain isotopes were concentrated by biota to a much greater extent than the concentration of that isotope in water. From these observations came the concept of the concentration factor (CF) such that

$$CF = \frac{C}{C'}$$

where C and C' are the concentration of the radionuclide in the aquatic organism and in the aqueous medium respectively. The concept is also applicable to stable isotopes (Polikarpov, 1966).

Calculation of concentration factors for heavy metals revealed significant differences between species of the same genus and between strains of the same species (i.e., *Nostoc*). Some species regularly had concentration factors of 1×10^4. In general, young cultures exhibited very much higher concentration factors than old cultures. Most of the metal removed by algae can be removed by a rinse with 0.01 M ethylenediaminetetraacetic acid (EDTA) or 0.1 N nitric acid (HNO_3). This information suggests that surface adsorption sites are the principal repository for the metallic ions or particles.

The ability of algae to remove metals is generally in this order: mercury > lead > cadmium. Neither zinc nor arsenic was removed significantly at any pH during a three-hour exposure. The presence of chelating agents in the medium (such as EDTA) inhibited the removal of the heavy

Table 1. Algal-Metal Combinations Used in Batch Studies

		Cations							
Alga	*Age (days)*	*As(III)*	*As(V)*	*Cd*	*Cu(II)*	*Hg(II)*	*Ni(II)*	*Pb*	*Zn*
Chlamydomonas	12	-	+	-	-	-	-	-	-
Chlorella	12			-	-		-	-	
Spirogyra	12		+	-	-	-	-	-	
Ulothrix	12	+	-	-	-		-	+	-
Ulothrix	20	-			-		-	+	
Gleotrichia	12				-		-	-	
Gleotrichia	20	-							
Gleotrichia	40	-							
Nostoc *31*	40	-	-						
Nostoc *586*	12	-	-	-	-	-	-	-	
Nostoc *586*	20	-							
Oscillatoria	12	-	-	-	-	-	-	-	-
Oscillatoria	20	-							

metals. Calcium and magnesium were not effective competitors for the binding sites of mercury, lead, and cadmium. There was remarkably little effect of pH on metal accumulation in the range of pH 5 to 8, when young cells were employed. Lead was the principal exception because it was removed more efficiently at pH 4 to 5 than at other pH values.

The removals of lead and mercury from nutrient solution by algae are found to be rapid phenomena, usually accomplished in three hours or less at room temperature. If the cells were placed in buffer after the initial adsorption of lead, a limited, slow release of lead occurred for a few hours, perhaps while some surface polymer-lead complexes were released from dead or dying cells. Mercury was removed from solution in nearly identical fashion by two strains of *Nostoc* and showed little evidence of being released. In the control wells without algae there were reproducible losses of ^{203}Hg that occurred within the first 24 hours at pH 6. This may be related to reports in the literature claiming volatilization of mercury by algae.

Chlamydomonas (a green flagellated form) proved to be dramatically superior to all other species in its ability to remove lead. Concentration factors for the organism of 1.9 x 10^4 were noted. This organism showed essentially the same concentration factor for lead in the pH range of 4 to 9. In other experiments, *Ulothrix* and *Chlorella* had concentration factors for cadmium greater than 10^4.

The empirical successes of the algal-meander system for removing lead from surface waters can be explained in part by the concentration and sequestering of lead and cadmium on the surface of algal cells. Very little heavy metal was leached from these cells at pH 5 to 9 in the presence of divalent cations and other inorganic constituents of algal growth media.

Results

Algal Growth

Algal growth for 20 species provided a representative selection of algae for the experiments. Some species proved impossible to culture and others exhibited unusual rates of growth. Table 2 reveals that no growth was obtained from any form in soil-water media. The choice of African violet potting soil was probably unfortunate because this soil is high in humus. Success with this medium depends on the selection of a garden soil with a medium humus content.

A few algal forms were characterized by unusual growth rates. *Mougeotia* and *Zygnema* grew only slowly and to a low final biomass. *Nostoc* 31, *Nostoc* W and *Gleotrichia* exhibited a long lag phase. For each of these forms, inoculation was followed by about 15 days of apparent inactivity. After this period, growth to a useful final biomass was rapid. For these forms, then, no young culture data are available.

Table 2. Sources and Cultivation of Algae

	Algae	Source*	Type	Growth on media† B	D	SW
A.	*Baccillariophytes (diatoms)*					
	Navicula pelliculosa	*UTEX 668*	*Pennate diatom*	-	-	-
B.	*Chlorophytes (green algae)*					
	Chlamydomonas *sp.*	*Dr. C. Kuehnert Syracuse University*	*Unicellular, 2 flagella*	-		
	Chlorella pyrenoidosa	"	*Unicellular*	-		
	Chlorotylium *sp.*	*Dr. N. Lazaroff SUNY Binghamton*	*Filamentous*	-		
	Kirchnerella *sp.*	"	*Colonial, enclosed in gelatinous matrix*	+		
	Mougeotia *sp.*	*UTEX 758*	*Filamentous, planktonic*	+		
	Scenedesmus obliquus	*UTEX 2016*	*Colonial, 4-8 cells, planktonic*	+		
	Spirogyra *sp.*	*Dr. N. Lazaroff*	*Filamentous, planktonic*	+		
	Ulothrix fimbrinata	*Dr. N. Lazaroff*	*Filamentous, benthic*	-		
	Zygnema	*UTEX 923*	*Filamentous, enclosed by mucilaginous sheath*	-		
C.	*Cyanophytes (blue-green algae)*					
	Gleotrichia *sp.*	*Dr. Lazaroff*	*Colonial*	-		
	Nostoc muscorum *A*	"	"	-		
	Nostoc *F*	"	"	-		
	Nostoc muscorum *H*	"	"	-		
	Nostoc *L*	"	"	-		
	Nostoc muscorum *W*	"	"	-		
	Nostoc *31*	"	"	-		
	Oscillatoria *sp.*	"	"	-		
	Nostoc *586*	"	"	-		
	Schizothrix calcicola	"	"	-		
D.	*Mixed Cultures*					
	Cazenovia Lake			-	-	
	Onondaga Lake			-	-	

**University of Texas Culture Collection and Identification*
†B = Bold's medium, D = diatom medium, SW = soil water medium
+ = success
- = failure

Batch Studies

The results of the batch studies are presented in Figures 1 through 3. The figures show the concentration of metals in the sample as a function of the time the samples were withdrawn from the culture. It should be noted that, for reasons of clarity, not all data points are shown on the figures.

Arsenic III—The data show no obvious trends in the removal of arsenic III. The highest removal (about 35%) was accom-

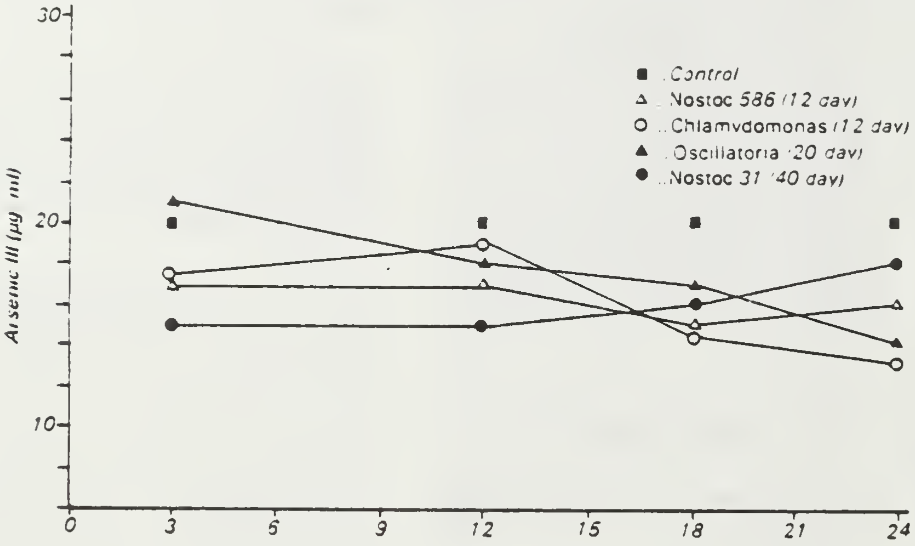


Figure 1. *Uptake of arsenic (III) by various algae.*

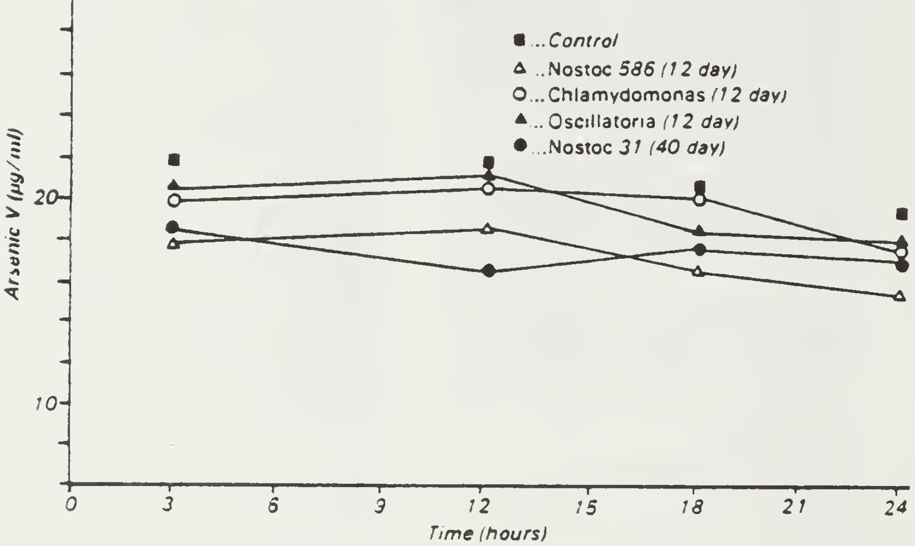


Figure 2. *Uptake of arsenic (V) by various algae.*

plished by *Chlamydomonas*, which also had the lowest biomass (0.12 mg/ml).

Arsenic V—There are no obvious trends in the removal of arsenic V. Most experimental values are too close to the control value to be considered significantly different. The lowest experimental value (16 µg/ml, compared to a control value of 20 µg/ml) was attained by *Nostoc* 586, which had among the highest biomass (0.40 mg/ml).

Cadmium—Cadmium was likewise not dramatically removed by the algae used in this part of the study. The lowest experimental values (about 10 µg/ml) were achieved by *Ulothrix*, which had the highest biomass (0.34 mg/ml). That the acid rinse for both *Ulothrix* and *Nostoc* 586 (with the next lowest experimental value) had high concentrations of cadmium indicates a surface adsorption mechanism for cadmium removal.

Copper—The highest removal of coppe about 30% compared to the controls) wa attained by *Gleotrichia*, which had biomass of about 0.14 mg/ml. This alga though usually a dark brown mass o filaments, turned greenish on exposure to copper.

Lead—Lead appeared to be removed by all the forms studied in this experiment with removal (compared to the 18-hour control) of from 15% for *Spirogyra* to about 87% for *Oscillatoria*. The green filamentous *Ulothrix* showed high values of lead removal, and the morphologically similar *Spirogyra* showed values little different from the controls, even though both algae had nearly identical biomasses. The high values of lead in the acid rinses suggest again a surface adsorption.

Mercury—The most dramatic removal of mercury was accomplished by *Nostoc* 586, which had an experimental value of 6 µg/ml as compared to the control value of 34 µg/ml after only three hours. Again the values of mercury in the acid rinses were high.

Nickel—Although all algae seemed to exhibit some removal of nickel (17% to 37% after 24 hours), no trends could be discovered from the data.

Zinc—The algae that seemed to accumulate zinc were *Spirogyra* (with 41% removal after 18 hours) and *Nostoc* 586 (with 37% removal during the same length of time). Again, the acid rinses of these two algae had high values of zinc, suggesting surface adsorption sites.

Discussion of Project Results

With the exception of zinc, these results show reasonably good agreement with the literature, with all concentration factors between studies agreeing within a factor of 2 to 3

Previous studies also examined the kinetics of heavy metal accumulation by algae and in general show that uptake was an extremely rapid phenomenon. The results of the 24-hour experiments in this study clearly confirmed the earlier observations in this regard. The negative results for the cadmium experiments cannot be explained at this time

One obvious manner in which the present study extends previous work is the calculation of concentration factors for species of algae previously unstudied. These data were obtained under identical conditions and record both intraspecific (in the case of *Nostoc*) and interspecific differences in heavy metal accumulation by algae. New data are provided on the effects of culture age, and initial pH

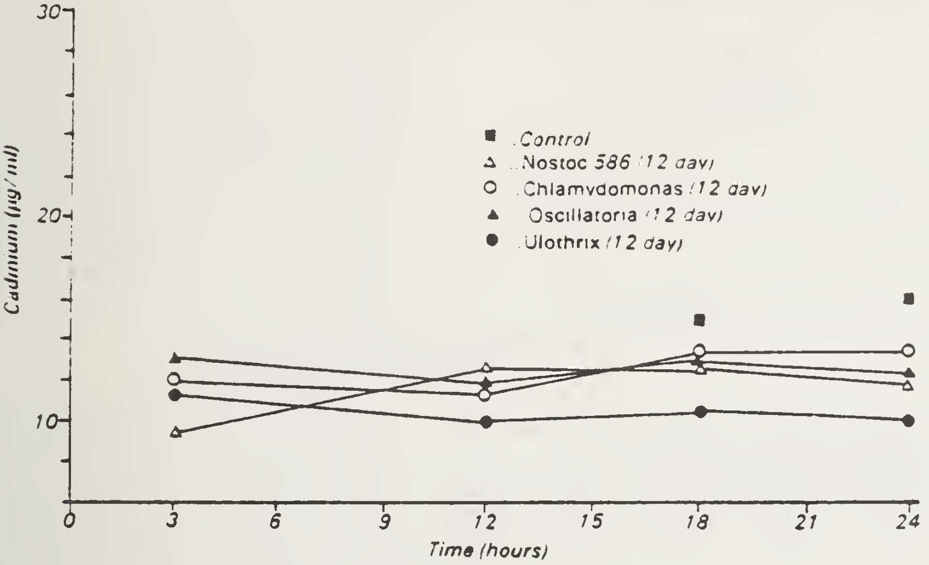


Figure 3. *Uptake of cadmium by various algae.*

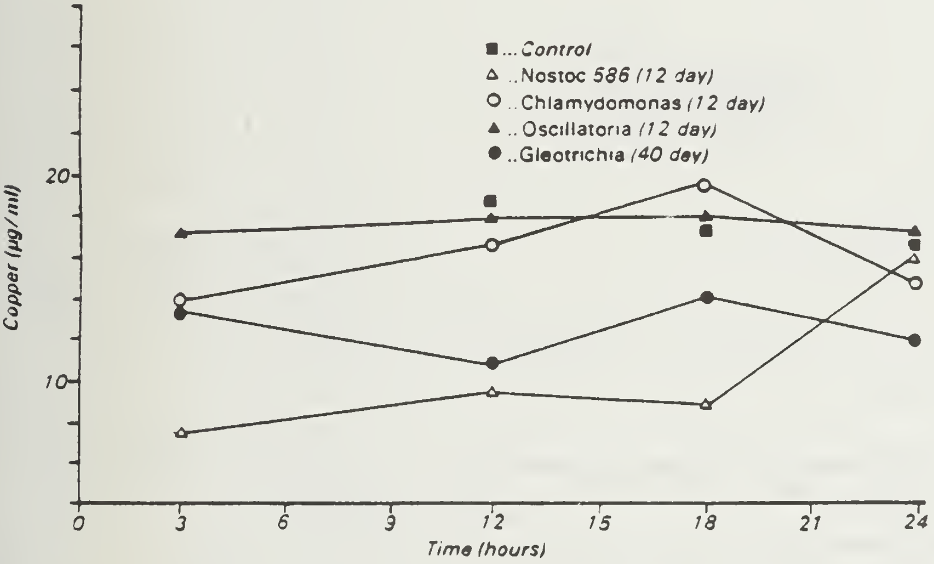


Figure 4. *Uptake of copper by various algae.*

during the labelling period, on the accumulation of heavy metals by algae.

The present study about doubles the number of algae for which concentration factors for cadmium have been determined. This is not only important to waste treatment applications, but also to environmental impact studies. Also noteworthy is the close agreement of concentration factors from the literature with those of this study, with CFs on the order of 10^3 common to both. What is not immediately apparent is the generally lower CFs for the blue-green algae. In fact, three 10-day old cultures of blue-green algae, *Nostoc muscorum* A, *Nostoc* H and *Schizothrix calcicola* did not remove cadmium significantly at any pH, while only one green algae, *Mougeotia*, showed such negative results. Although the total number of species examined is small, the present study suggests that green algae are somewhat more efficient at accumulating cadmium than the blue-green algae.

Concentration factors for lead are generally on the order of 10^3 to 10^4 for all algae studied. All the blue-green algae screened were successful at removing lead at least at one pH, while the diatom *Navicula pelliculosa* and the green *Chlorella* and *Scenedesmus obliquus* were successful at accumulating lead at any pH. *Chlamydomonas* proved to be the most efficient at removing lead from solution.

Mercury was again demonstrated to be concentrated avidly by most species of algae. Every organism screened in this study removed mercury at least at one pH, with concentration factors on the order of 10^3 and 10^4. Algae may be one of the most effective means for removing this element. Algae can reduce mercuric ion to elemental mercury which is subsequently volatilized to the atmosphere. The question might arise whether the same phenomenon occurred in these experiments, giving artifically high concentration factors. Although the possibility cannot be denied categorically, the short time scale of these experiments (three hours) and the quiescent conditions under which the plates were held would argue against loss of very much mercury to the atmosphere. This is especially true since most other studies employed aerated cultures and a time scale of several days. It has also been reported that the reducing factor(s) were extracellular. Since the algal cells in the present study were washed and resuspended in distilled water before introduction to the assay plates, the concentration of reducing factor(s) would be diminished, at least initially. However, the phenomenon of mercury reduction and volatilization by algae clearly deserves further study.

Another contribution of this work was the systematic study of the effect of pH on heavy metal accumulation. The studies cited from the literature were generally field observations, during which the pH of the surroundings varied naturally, or were laboratory studies where the culture media characteristically determined the pH of metal uptake, and therefore, uptake across a wide variety of pH conditions could not be determined. In general, those algae which are most proficient at removing metals will remove them over a wide pH range. For example, *Chlamydomonas* removes lead across a pH range from 4 to 9 at about the same efficiency (0.69-0.80) while the less effective alga *Mougeotia* removes lead only at pH 9 and

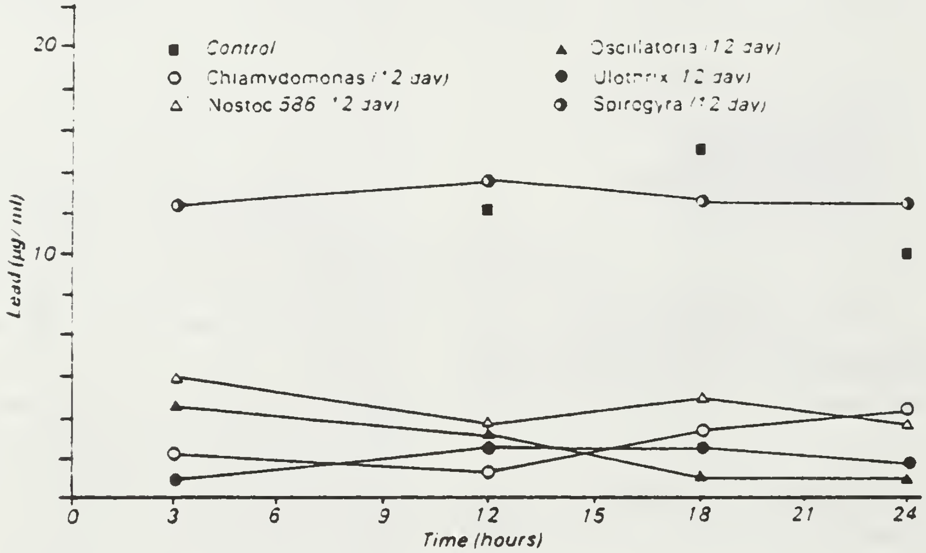


Figure 5. *Uptake of lead by various algae.*

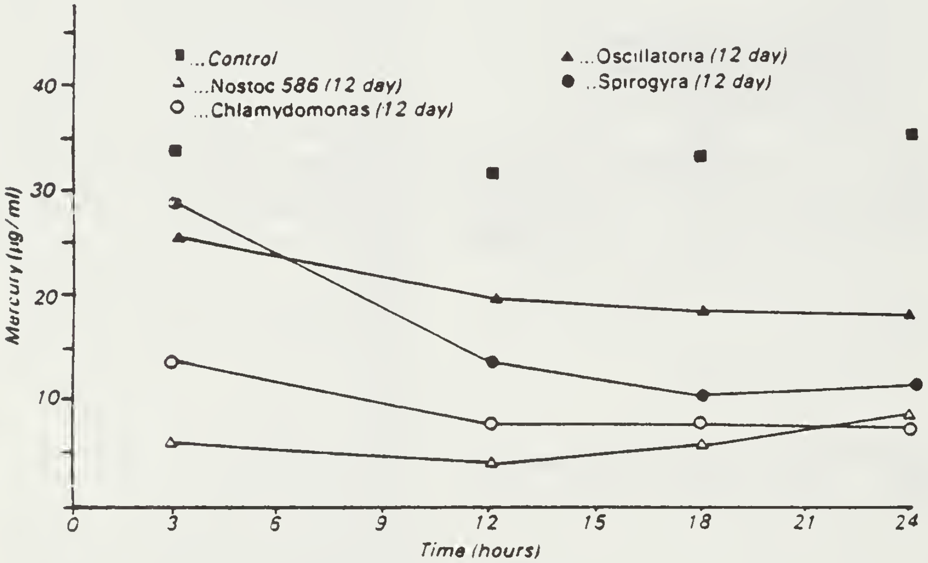


Figure 6. *Uptake of mercury by various algae.*

then only at an efficiency of 0.29 Clearly *Chlamydomonas* is more competent at removing lead from solution.

Other observations made during this study tend to confirm and extend suggestions made by earlier workers. It has been hypothesized that the flagella of *Platymonas subcordiformis* provided the sites for a significant fraction of the lead taken up by this algae. While this hypothesis was not specifically tested in the laboratory, the dramatic superiority shown by *Chlamydomonas* in removing lead, as compared to the other algae evaluated combined with the fact that *Chlamydomonas* was the only flagellated form used, argues for the importance of the flagella as sites of lead accumulation.

Perhaps one of the most important contributions of this work, however, was the adaptation and development of microtiter equipment, especially the Titertek™ supernatant collection apparatus to the study of the problem of algal uptake of heavy metals The technique and procedures developed during the course of this study have already provided usable data on a relatively limited number of variables. Future work will no doubt utilize the rapidity and sensitivity of the technique to accumulate more data covering a wider range of variables

Recommendations

The remarkable ability of selected algae to concentrate heavy metals on their cell surfaces suggests that the use of intensive algal culture may be a very practical way to reclaim wastewater and/or recover useful quantities of metals. Several directions for future research and development are clearly indicated before this potential can be realized:

1. The glycocalyx—i.e., the mucopolysaccharide and protein capsule—surrounding all algae must be isolated from metal-avid species and further studied for its biochemical structure, exchange capacities, and biphasic physical properties. With these data in hand, it is practical to search for organisms with glycocalyces having desirable properties for the adsorption of metals.
2. If algal beds are to be maintained on a continuing basis, it will be necessary to follow the reproductive capacity of the organism(s) in the presence of excessive levels of metal. In fact, it may be necessary to devise schedules for metal adsorption that are followed by regeneration at low metal levels.

   The present meander technology depends entirely on the presence of naturally occurring wild algae, probably growing as a mixed flora Since some of the species may have concentration factors in excess of 1×10^4 under certain conditions, and others may not concentrate metal at all, it appears profitable to encourage the former by selective algal farming. Simple enrichment culture techniques are feasible for the meander manager
3. A screening operation should be devised with the objectives of finding natural or induced mutants that a) have accumulation coefficients one or more orders of magnitude greater than wild types, b) exhibit greater selectivity for a particular metal ion than the wild types, and c) tend to

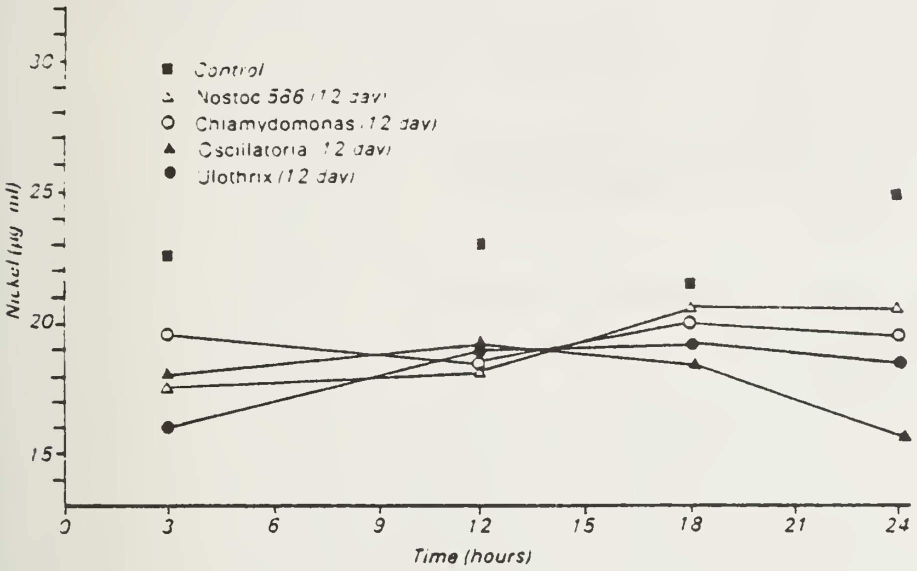


Figure 7. *Uptake of nickel by various algae.*

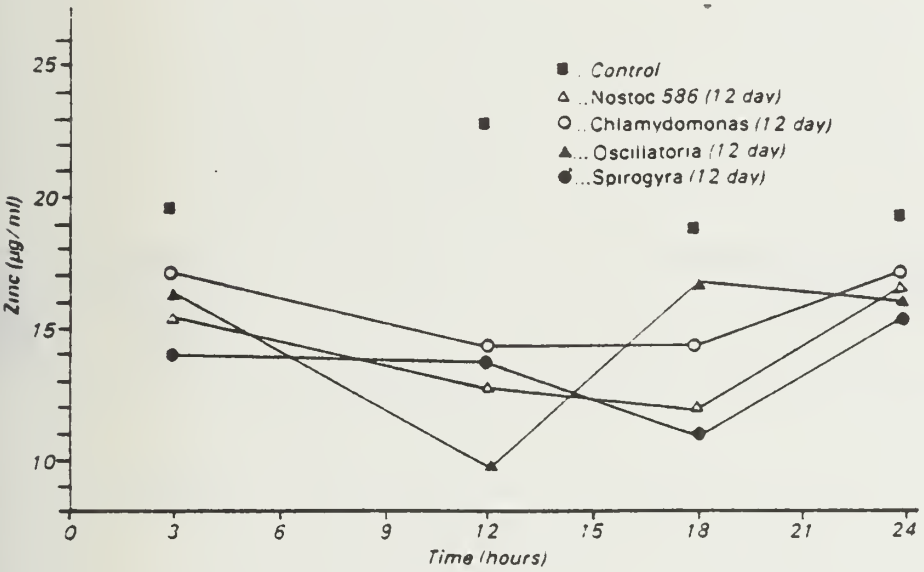


Figure 8. *Uptake of zinc by various algae.*

remain in their benthic form rather than in their free-floating form. The blue-green algae may be the better choice for this work because they are usually more metal-avid than green algae, and because they are haploid. The latter characteristic makes it easier to induce mutations and to select for variants than in diploid organisms.

4. Almost no data are to be found concerning the maintenance of beds of benthic algae on a continuous basis. Experiments are needed to learn the long-term consequences of heavy metal accumulation in such beds, to monitor detention and release of metals during chronic exposures, and to study the detachment of benthic cells coated with heavy metals.
5. Methods must be devised for systematically discharging metals, or for otherwise recovering them, from meander beds. Simultaneously it must be determined whether or not it is feasible to recycle the algal cells as inoculum or feedstock after they have been stripped of metal by chemical washing.
6. Investigation of practical questions regarding the suitability of metal-stripped secondary sewage effluent for agricultural purposes must be examined. Conversely, the efficacy of sewage as a dependable nutrient source for algae has not been established. Certainly, the presence of oil, cyanates, solvents, etc., could be expected to interfere with the productive synthesis of the glycocalyx adsorptive surface.
7. The effects of light, temperature, and salt concentration have not been evaluated on a continuously operating meander. Quantitative data have not been collected on the optimum output of glycocalyx because the factors which stimulate it are essentially unknown.
8. Future work should determine whether or not an appropriate substitute can be found for the algal cells in the meander (aggregates or other surfaces coated with semi-purified glycocalyx, for example). This search might provide a renewable and/or strippable surface that would eliminate some of the vagaries associated with the maintenance of open algal cultures.

Reference

Polikarpov, G. G. 1966. Radioecology of aquatic organisms (Translated from Russian by Scripta Technica). Reinhold, New York. 314 p.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1983/659-095/1907

J. Charles Jennett is presently with Clemson University, Clemson, SC 29631. J. E. Smith and J. M. Hassett are with Syracuse University, Syracuse, NY 13210.
***Hugh B. Durham** is the EPA Project Officer (see below).*

The complete report, entitled "Factors Influencing Metal Accumulation by Algae," (Order No. PB 83-149 377; Cost: $14.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA 335

Official Business
Penalty for Private Use $300

RETURN POSTAGE GUARANTEED

Third-Class
Bulk Rate

QUESTIONS POSED BY THE EXPANDED STEERING COMMITTEE

GROUP 1

First Cut

1. Would ore processing effort generate useful for water cleaning?

2. Is there really a supply demand for clean water (water/regulatory)?

3. What are definitions: Criteria for component problems - discharge limits of water throughout volume for ores - environmental impact?

4. Are there means on-site to enhance water - to improve feedstock?

5. Can a static condition be created in the Pit (isolating it) that allows it to clean itself, particularly if forced to view alternatives by economics?

6. Time urgency for developing a system for disposing of water? (refill aquifers net gain from precipitation alluvial)

7. When surface filtration plans for city will be required - location - capital improvement of this project?

8. What kind of bio-tech resources can remove metals from metal - then in turn be harvested? Can municipal waste be combined to enhance process?

9. Can an innovative approach on (mining) or processing side gain industry acceptance?

10. Where would money come from - what are the economic standards that have to be satisfied? Formulate several economic scenarios.

11. What are possibilities converting water - moving to the old settling ponds outside Anaconda for evaporation (gravity down to Silver Bow Creek)?

12. Can intensely polluted water go to combuster? Process hard ores?

13. Should old lime system be used as base and more improvements from there?

14. Is there enough mining potential (dumps and otherwise) to support an intergrated process/water system?

15. Is there a limit on time available to develop innovative approaches before state and EPA regulations take over?

16. Does potential summary of values (metals, water, etc.) appear sufficient to justify cost?

17. Will there be cooperation from ARCO, EPA, MRI, and local people?

18. Ownership of water liability and pumping (given liability)?

19. Is there a large open market for sulphur that can be created?

20. What regulatory hurdles have to be overcome?

21. How would effort be organized?

22. Can the hill be used for compressed air storage? (History says yes.)

23. Do we want to restrict this to commercially proven technology timeline market plan?

24. Who is the market? What is being sold; i.e. R&D, water?

25. What are the thermal dynamics of potential system?

26. How long does the system need to be in place (ore processing relationship longer than emergency response, but shorter than passage - biological response)?

27. Technological assessment for innovative application before economic evaluation or after?

GROUP 2

First Cut

1. Confirm water and mineral rights within the water. Negotiate with owners.

2. What is appropriate project structure?

3. Who are the players and what are their parts?

4. How will feasibility be determined?

5. What are the values of minerals in the water and the value of the water?

6. Characterization of water; i.e., inflow, sources, hydrology.

7. What are the technologies available and what are the costs?

8. To what extent are economics going to drive this project?

9. Arrest the rise of the water.

10. Identify how clean the water must be to meet the EPA standards.

11. Does pit control groundwater in Butte area?

12. Identify the problem.

13. How much risk is involved in this project?

14. Are we duplicating Superfund efforts?

15. Liability - environmentally and safety (define).

16. Can water cleaning process be integrated before processing?

17. How will water cleaning processes interface with mineral recovery?

18. Will water cleaning processes result in the production of toxic waste?

19. Are the products sellable?

20. Who pays for this - who contributes?

21. How would the process of water cleaning affect ownership and liability?

22. What are the implementation scenarios?

GROUP 3

First Cut

1. Quality and quantity of input over depth, season, and time?

2. What studies are required to determine 1. above?

3. How expensive a water system are we considering?

4. Is it economical to process the water?

5. Impact on air quality.

6. Can source of water to pit be reduced or eliminated?

7. What emergency plans are needed to handle groundwater contamination?

8. Start by stabilizing depth of pit.

9. Start either on top or on bottom.

10. What are the present biological characteristics of the water?

11. How much dollars can be expected from EPA or others?

12. What will happen if nothing is done?

13. What market is there for clean water?

14. What can be added to water to mitigate present conditions or augment future recovery?

15. What federal standards need to be met for different uses?

16. Following treatment, what happens to residue?

17. Technology exists to either clean or extract:
    a. Dilute - RO - Lime
        ED
        Modified Freezing
    b. Concentrate
        Modified Freezing
        Lime

18. Phasing project to encourage future funding.

19. What goals are we trying to meet as a group?
    - employment
    - end use
    - cleanup
    - Montana institutions and companies gaining experience and preparing for growing waste treatment industry
    - demonstration

20. Is it cheaper to mine liquids or solids?

21. How do we organize, manage, and control this project?
    - politics
    - science
    - technology

22. Who has ownership, responsibility, and liability? How can or should this be transferred to HRI?

23. Who is going to "champion" the project over the long haul?

24. Budget exploratory technologies.

25. What new products might be produced?

26. What sources are there for R&D funds?

27. Go deep for zinc (most marketable today).

28. Need to produce 100,000 to 200,000 tons.

29. What resources are available? Where? Mineralogy?

30. Would Chile's ENAMI model work?

31. What form would an integrated plant take?

32. Who is going to develop new markets for products?

33. Who is committed to this project long enough?

34. How about a research park?

GROUP 4

First Cut

Category:

I. Philosophy why HRI? Motives who asked is a problem going to occur?
II. Quality of the water in the pit problem? Why? How severe?
III. Technology
IV. Economics to benefits
V. Liability
VI. Organization

1. What types of guidelines for discharge water?

2. Can the problem be ignored?

3. Will the pit backfill?

4. Look into specific gravity milling to upgrade marginal ore bodies.

5. Who owns the environmental liabilities?

6. What is the motive of all this?

7. The long-term nature of the enterprise, economics, and physical constraints. How to manage long-term recovery and cleanup.

8. How much water? Where will it go?

9. Who will cooperate?

10. Any need to treat the pit?

11. Look into possible smelting techniques for Butte area ore.

12. What environmental liabilities will HRI incur?

13. Is it realistic to create a process to treat water, ore, concentrates?

14. What profit versus nonprofit?

15. What will be EPA response? Their role in this?

16. Where are long-term dollars coming from?

17. What happens if we neutralize water in pit now?

18. Study permeability of alluvial zones. Will it clean itself in low permeability zones?

19. Is this project set up to clean the water or to fund research?

20. If there is a research there, which is economically viable, will HRI have any role?

21. Social and political incentives for the project.

22. If project is unfeasible, what happens to pit then?

23. Where is water coming from?

24. Will this create even larger liabilities later?

25. What happens to our plan if underground mining resumes?

26. Is Superfund money being looked at or will it be politically acceptable?

27. Is there economical value of the resources?

28. Externally costs of all cleanup technologies?

29. What will be done with tailings?

30. Can water be used as is for existing industries? New industries?

31. Is this resource for sale?

32. Innovative research into our present resource to make it economical.

33. Strive to minimize state and federal participation.

34. Is HRI going to have access to look at or evaluate this resource?

35. Relation to downstream reclamation and recovery project.

36. Is this project designed to prevent water rising to alluvial level?

37. Can metals be concentrated at the bottom of the pit?

38. Why do we have HRI? Economic, philosophical, political, research, environmental?

39. Need to research into handling high arsenic ores in this part of Montana.

40. Can water flow be stopped?

41. Will this activity HRI interface with current mining and milling activities?

42. What is the best form for metals recovery?
    hydroxides
    carbonates
    sulfides

43. Can water be recirculated above the mine?

44. Role of oxidation in leaching or underground sources.

45. Need substantially reducing environment in the underground.

46. Role of deep aquifer.

47. Role of neutralization and dilution of water from above the pit.

48. Quality of water before mining 150 years.

49. If we leave everything alone, will water return to neutral and gain in quality?

50. Berkeley iron may have no value.

51. Let water build and neutralize itself; avoid solids problem.

52. Let pit fill, treat in pit, become stable.

53. Aerate water, precipitate metals.

54. No for every scenario.

55. Slime the gravels before aquifer run tailings into seal.

56. Water comes from other sources maybe okay as of 150 years ago.

57. Understand in variations in water quality in the U.S.

58. Will leaving everything alone bring back quality so long as other groups and government agencies do not interfere?

59. Is the state asking for unreachable goals?

60. Are mining permits being denied because of unattainable water quality demands, forever?

61. Is financing being denied by this forever?

62. Will levels of required water quality be ungraded beyond economic industrial technological levels.

63. Will variances be granted? Will rules be changed later?

64. What is perceived as a problem downstream?

65. Who drives whom out? Water sensitivity and allergy.

GROUP 1

Second Cut

1. Technology assessment or economics first.

2. Time considerations how urgent - pit/aquifer - how much leadway for innovation before direct regulations? How long should system be sustained?

3. Economics: value/cost supplies/demand; evaluating some outputs.

4. Definition of component problems; regulation, environmental impact, product specification.

5. Where will the money come from through all phases?

6. What are the possibilities of moving water to Anaconda settling ponds?

7. How would the effort be organized?

8. Are there means on-site to enhance dynamics favorably?

9. Should the old lime system be used as a base to start with?

10. Cooperation by ARCO, EPA, MRI, and local people with water liability?

11. Who is the market? What is being sold? (R&D, metals, water)

GROUP 2

Second Cut

1. Payers, contributors: roles and responsibility.
2. Regulatory guidance and criteria.
3. Downstream liabilities risk.
4. Water and mineral rights ownership.
5. Who are the funding sources?
6. Define the problem and set objectives.
7. Characterization of the water in the pit and sources.
8. Identification of technologies.
9. Criteria for evaluating technologies.
10. Select and prioritize technologies (for assumed set of objectives).
11. Prepare an operation and management plan (research development demonstration) - technology adaptation.

GROUP 3

Second Cut

1. Quality and quantity of input over depth, season, and time.
2. What emergency plans are needed to handle groundwater contamination?
3. Starting either on top or bottom.
4. How many dollars can be expected from EPA or others?
5. How do we organize, manage, and control this project (politics, science, technologies)?

GROUP 4

Second Cut

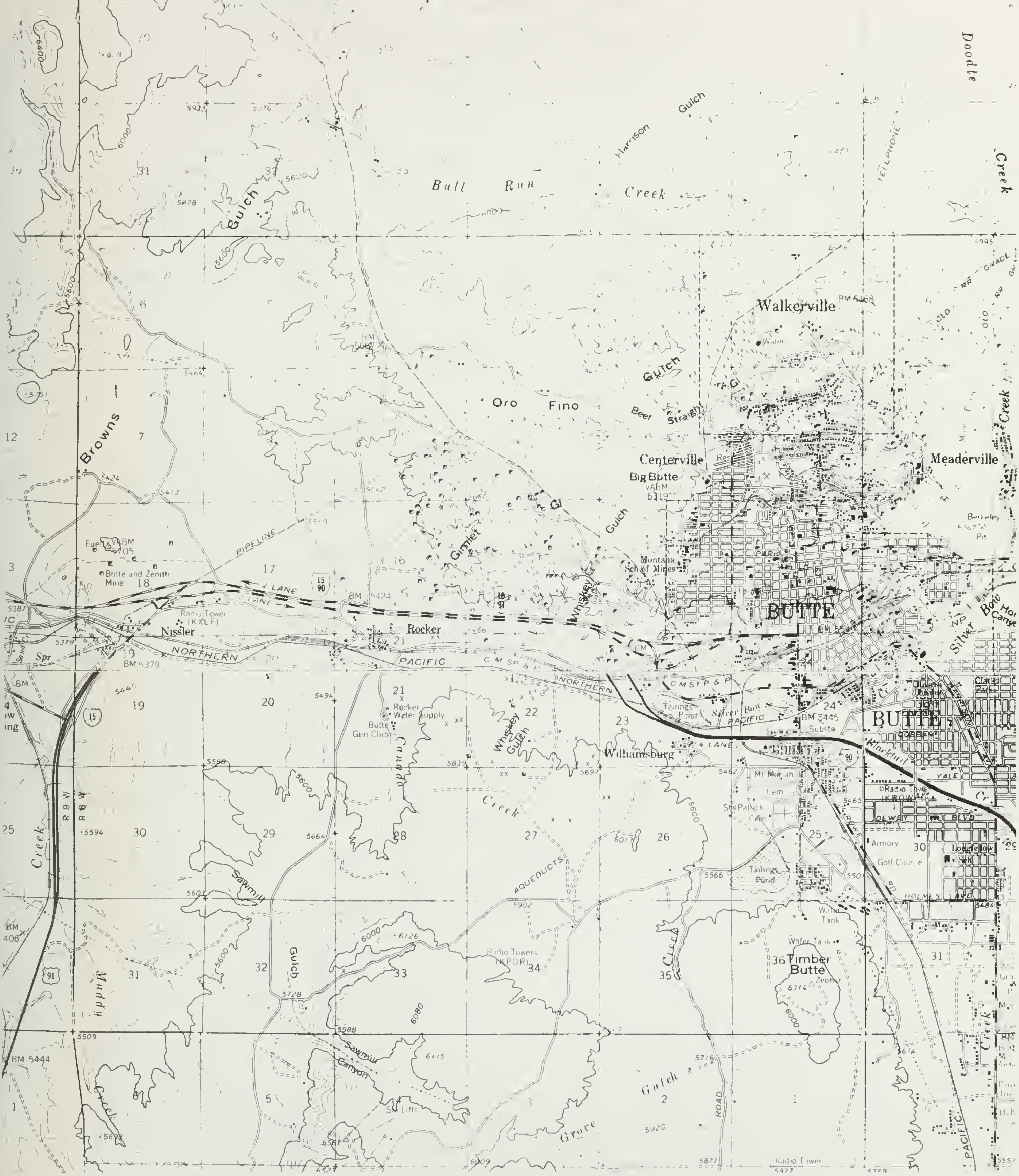
1. What are the objectives of HRI? Make them consistent with other public and private organizations.

2. Who is responsible for liabilities? Who may obtain them?

3. Is there a resource; is it available? Do water rights include minerals?

4. Can new technologies be developed that would enhance the resource and/or solve the problem - if one exists?

APPENDIX



SCALE 1:62500

1 ½ 0 1 2 MILES
3000 0 3000 6000 9000 12000 15000 18000 FEET
1 .5 0 1 2 3 4 KILOMETRES
GN
MN
1°10'
21 MILS
18½°
329 MILS

NATIONAL GEODETIC VERTICAL DATUM OF 1929

UTM GRID AND 1961 MAGNETIC NORTH

MONTANA

BUTTE WATER COMPANY
124 WEST GRANITE STREET - P.O. DRAWER 398
BUTTE, MONTANA 59703-0398

TO: John Driscoll **DATE:** September 22, 1986

FROM: J. W. Chelini **SUBJECT:** Master Plan

We considered many factors and options prior to selecting our proposed plan. Consideration was given to the following needs and in this order.

1. Water Production By Area
2. Storage By Area and Water Quality
3. Existing Transmission System
4. Functional
5. Distribution System
6. Rate Shock to Consumer
7. Methods to Finance
8. Timetable to Accomplish
9. Future Water Filtering
10. Options
11. Our Master Plan

Enclosure:

2 - Maps

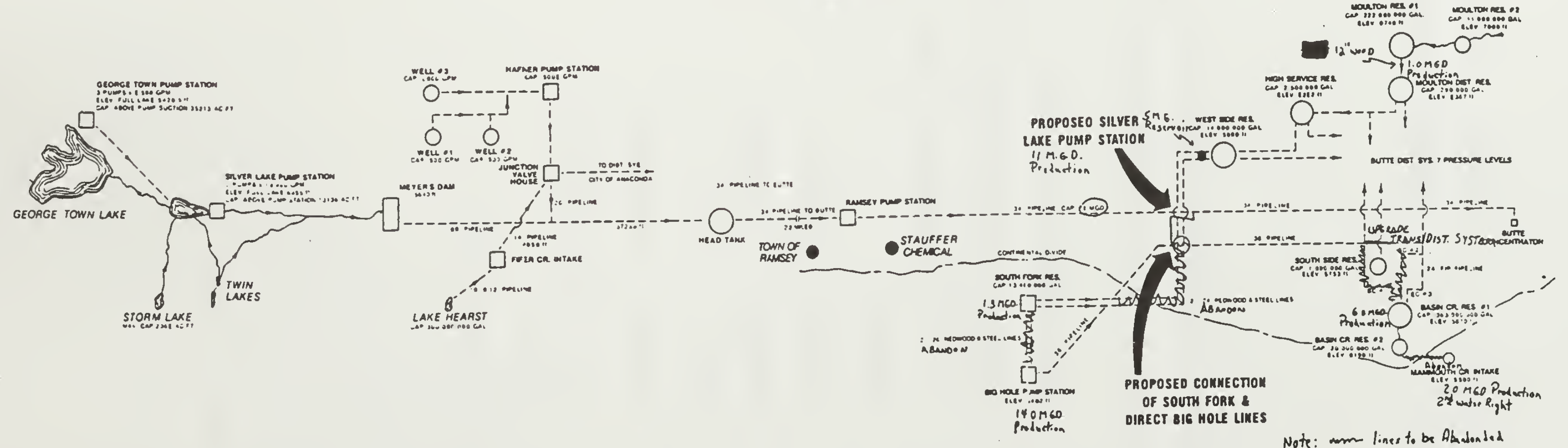
1 - Fact Sheet

1 - Water For Thirst Cities

F'gure 2

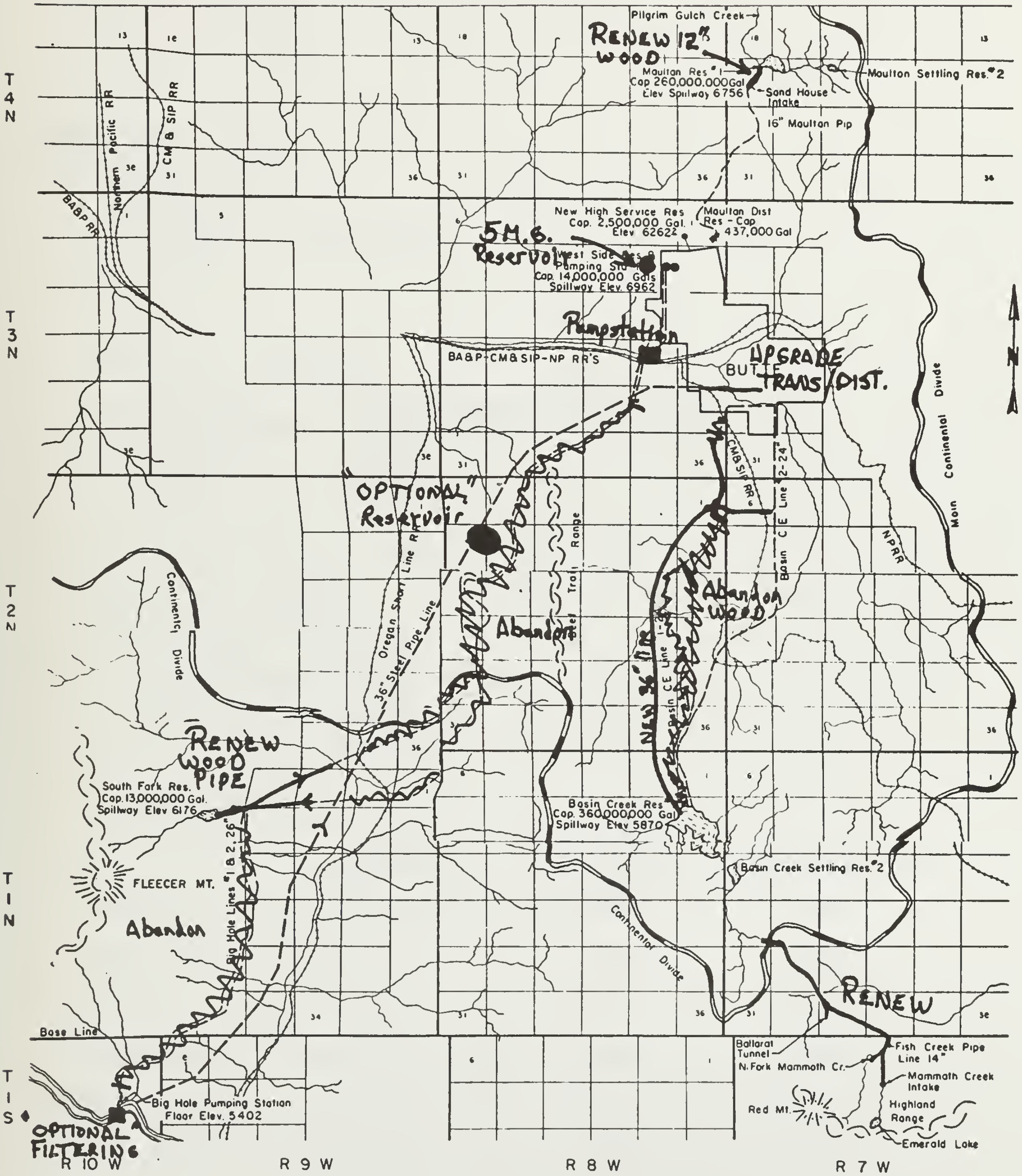
SCHEMATIC REPRESENTATION OF SILVER LAKE & BUTTE DISTRIBUTION SYSTEM

BUTTE WATER COMPANY



Note: ~~~ lines to be Abandoned

UPGRADE EXISTING SYSTEM



BUTTE WATER COMPANY

SUPPLY SYSTEM

FACT SHEET

WATER FACTS

Community Needs

Average	13 M.G.D.
Peak	29 M.G.D.

Sources and Production

Big Hole	+14 MGD	(Except April, May, June)
Basin Creek	6 MGD	(Second Water Rights on 2 MGD)
Moulton	1 MGD	
Total	21 MGD	

Transmission Capacity

Big Hole	+14 MGD
Basin Creek	15 MGD
Moulton	1 MGD
	30 MGD

Storage Capacity

	Gallons	# of Days	Water Quality
Big Hole	14 M.G.D.	275 Days	Poor
Basin Creek	360 M.G.	24 Days	Good
Moulton	260 M.G.	260 Days	Good
Southfork	13.0 M.G.	3.7 Days	Fair
High Service	2.5 M.G.	2.5 Days	Good
West Side	14.0 M.G.	2 Days	Fair

Transmission Leakage could be 50% from the wood lines.

Big Hole Wood	3.5 M.G.D.	1.75 M.G.D.
* Basin Creek	10 M.G.D.	5.0 M.G.D.
Total		6.75 M.G.D.

* Loss is restricted to heavy-use times as the source only produces 6 M.G.D. If we just stop the leaks, we have not solved the water quality issue or the storage issue.

Time Table

We need the next years construction season so we must commit with, or without, your input by January 1, 1987. The system may not last another year without major system failure.

Production does not equal consumption during peak periods. Storage is inadequate to our consumption.

Present Water Management Plan

1. Store as much water as possible in Basin Creek Reservoir -- 100% full June 30.
2. Use Big Hole water when possible and save other resources.
3. Pump water from Big Hole when possible to the city and surplus to Basin Creek Reservoir (September to April) to recharge.

Considerations Affecting Management Plan

Some water must be supplied by Basin Creek Reservoir at all times to service south of city and pressurize from the south.

Moulton must be used to service Walkerville and Centerville.

Pumping water into Butte and up to Basin Creek Reservoir places added pressure on system causing breaks.

The Big Hole wood lines service the West Side Reservoir and the west side of Butte. No water from Big Hole steel line can be pumped to the West Side at present. We can pump 3.5 M.G.D. through wood lines; when we attempt to pump more gallons, the additional pressure causes pipe blowouts.

Our problems start in April when the turbidity of the Big Hole water is high and we can only use 3.5 M.G.D. The wood line water is the only water that can be settled at the Southfork Reservoir. We use the 1 M.G.D. from the Moulton and the other 8.5 M.G.D. must come from Basin Creek Reservoir. Therefore, the Basin Creek Reservoir supplies over 50% of our water for three months (April, May and June) and about 50% for July and August. The limited production and storage from this source presents problems during dry periods.

Where we have water production, we don't have transmission or settling reservoirs; and where we have storage, we don't have water production or transmission.

Silver Lake

Production	+11 M.G.D.
Transmission	+11 M.G.D.
Storage Capacity	720 Days
Water Quality	Excellent
Transmission Leakage	Minimal

EXHIBIT #1

WATER PRODUCTION

(Map Attached)

We have five (5) areas available to Butte with water production.

1.	Big Hole River	14	M.G.D.
2.	Basin Creek	6	M.G.D. - 2 M.G.D. is second water rights
3.	Moulton Reservoir	1	M.G.D.
4.	Southfork of Divide Creek	1.35	M.G.D.
5.	Silver Lake	11	M.G.D.

Butte requires 13 M.G.D. Average

29 M.G.D. Peak Capacity

EXHIBIT #2

STORAGE

We have storage from the named production in the following areas.

	GALLONS	DAYS STORAGE	WATER QUALITY
Big Hole River	+3,850 M.G.	275 (1)	Poor
Basin Reservoir	360 M.G.	24 (2)	Good
Moulton	260 M.G.	260	Good
Southfork of Divide	13 M.G.	3.7	Fair
High Service Reservoir	2.5 M.G.	2.5	Good
West Side Reservoir	14 M.G.	2	Fair
Silver Lake	+4,015 M.G.	365	Excellent

(1) We cannot use water from the Big Hole because of water quality during spring run-off; 90 days estimate.

(2) Basin Reservoir has transmission capabilities of 15 M.G.D. for about 24 days. The area only produces 6 M.G.D., and 2 M.G.D. is second water rights from across the Continental Divide.

EXHIBIT #3 **EXISTING TRANSMISSION SYSTEM**

1.	Big Hole	+14 M.G.D.
2.	Basin Creek	15 M.G.D.
3.	Moulton	1 M.G.D.
4.	Silver Lake	18 M.G.D. - 11 M.G.D. Available

1. The Big Hole River has two wooden lines built in early 1900's which should have a capacity of 5 M.G.D. each. We can only run one pump or 3.6 M.G.D. total through both lines. If we start an additional pump, the lines rupture because of the extra pressure. The water from the wood lines can be used during the spring run-off by settling action at the South Fork Reservoir. The one steel line has 14 M.G.D. capacity, but cannot be used during spring run-off as it comes direct into the homes without settling facilities. At present we must rely solely on the two wood lines from Southfork Reservoir to get water to the West Side Reservoir.
2. Basin Creek has two wood lines built in the early 1900's, and one steel constructed in 1964. They have the capacity to carry 5 M.G.D. each, or 15 M.G.D. The storage and water production is limited, so they can transport 15 M.G.D. for a short period of time.
3. Moulton can transport 1 M.G.D. to the northern part of the city.
4. The Silver Lake line can transport 18 M.G.D. at present and could transport up to 23 M.G.D. by adding more pumps and increasing the pressure. The line was completed in 1965 and is of premium construction. At this point, the mine needs 7 M.G.D. which allows B.W.C. the other 11 M.G.D. of high quality water with almost unlimited storage capabilities.

EXHIBIT #4 **FUNCTIONAL**

1. Big Hole
2. Basin Reservoir
3. Moulton
4. Silver Lake

The functional roles the Big Hole and Basin Reservoirs play do not coincide with mother nature. Example, the Basin Reservoir function is to store water for the peak demand in June, July and August. Because the Big Hole's water quality during the run-off, we are forced to use the Basin Reservoir as our main supply during April, May, and June; therefore, reducing the level of our storage. Because of limited storage and production, water restrictions become mandatory. We also attempt to pump water from the Big Hole into our distribution system back out through the Basin Reservoirs transmission lines to help fill the reservoir. With some lawn sprinkling in Butte, we can use all three pumps at the Big Hole. However, without sprinkling, we must cut back to two pumps as the pressure increase causes unlimited breaks in our distribution and Basin transmission system. So we are limited in our ability to place surplus water from the Big Hole into the Basin Reservoir.

Silver Lake and Moulton do not have functional problems in regards to storage, water production, and transmission.

EXHIBIT #5 DISTRIBUTION SYSTEM

The distribution system is very old and badly in need of upgrading. We have seven pressure zones due to the vertical drop within our system. We can get pressures from 185 p.s.i. to 8 p.s.i. in some areas. There is no transmission line entering the city from the east, so most of our low pressure problems are on the east side of the city as the elevation climbs. We have a very low area of our system centered along the interstate highway and Silver Bow Creek. Sand and sediments in this area are common. The sediment is due to Big Hole water without settling or filtering. The sand should be eliminated soon, as we notice a reduction in sand calls, and the sand size is large, indicating the fine particles have washed through.

EXHIBIT #6

RATE SHOCK

Our present proposed master plan indicates about 120% increase over twelve years, with the largest increase about 25% in one year. This does not include filtration if enforced during this time period.

The plan also provides a noticeable change in water quality and we think water pressure, when the rate increase occurs. If not water pressure, we have more options available to help solve the pressure problem.

Our plan does not include metering all homes; but hopefully, we can fit it in without causing rate shock over a period of time.

EXHIBIT #7

FINANCING METHODS

We intend to purchase the Silver Lake System from Mr. Washington for nothing down and no principal payments in the near future. The increased base shall provide additional cash flow and allow for additional financing. The generated cash flow shall be used to begin the upgrading of the distribution system, as well as equipment and reservoirs.

EXHIBIT #8

TIMETABLE

Butte Water Company intends to have a declaratory ruling from the Commission by November 15, 1986, in regards to the methods which will be used to calculate the value of the Silver Lake System. This is necessary for Butte Water Company to project cash flow and place a timetable on additional projects and allow engineering time.

Butte Water Company shall award a contract for the engineering and construction by January 1, 1987, for a pumping plant to handle the Silver Lake water as it enters Butte.

The pump station should be used, and useful, by October 1, 1987; and we intend to file a rate case in March of 1987.

In the following years, we shall upgrade the distribution, reservoirs, equipment and buildings. Starting in 1989, the capital budgets indicates $1,100,000, $620,000 and $1,800,000 respectively. Filtering, or total metering, are not included, as we must provide a product as soon as possible at an affordable price.

EXHIBIT #9 **FILTERING**

Surface water filtering shall become mandatory in the future. Reducing the use of our poorest quality water, the Big Hole River, might allow us additional time. The estimated cost for filter construction at this time is .50¢ per gallon, or about $15 million for our system. If we maintain four systems as we have now, we would be required to have three shifts per location, seven days a week. The fewer water sources would reduce costs to operate. With Silver Lake it is also possible to have two major sources.

EXHIBIT #10

OPTIONS

(Map Attached)

1. Abandon the two wood lines from the Big Hole, and pipe the 36" steel up to the Southfork Reservoir. This would produce 14 M.G.D., 12 months per year, of fair quality water. A pump station would have to be constructed in Butte to pump water up to the West Side Reservoir.

2. Abandon the two wooden lines from Basin Creek, and rebuild one large, or two lines the same size. Water production and storage from this source is limited. The 2 M.G.D. from Fish Creek has second water rights, and the system bringing it over the Continental Divide would need to be upgraded.

3. Moulton Reservoir would supply the 1 M.G.D. with some upgrading.

4. Southfork water could be added to Big Hole water to help the water quality. Storage time would be inadequate for proper treatment, unless the reservoir was enlarged.

5. An additional reservoir could be constructed on the Big Hole steel line. Permitting delays, cost, and time-lag involved make new or reconstructed dams questionable.

6. An option to #1 is to filter the water at the Big Hole River and eliminate storage. Costs would triple, but solve long-term filtration.

EXHIBIT #11 **MASTER PLAN**

The Silver Lake system would be operational by October 1, 1987, supplying 11 M.G.D. into a pump station for distribution into the city. Butte Water Company will purchase the Silver Lake system prior to accepting contracts for engineering or construction of the pumphouse. When the Silver Lake system and pumphouse is used and useful, the rate base shall be increased. Most of the wood lines from the Big Hole and Basin Reservoir would be abandoned. The 11 M.G.D. from Silver Lake would replace the 3.6 M.G.D. from the Big Hole and the 10 M.G.D. from Basin Reservoir.

Our first phase system would consist of the 11 M.G.D. from Silver Lake, 5 M.G.D. from Basin Reservoir, 1 M.G.D. from Moulton, and up to 14 M.G.D. from the Big Hole River, for a total peak capacity of 31 M.G.D. This would replace our present peak capacity of 14 M.G.D. from the Big Hole, 15 M.G.D. from Basin Creek, and 1 M.G.D. from Moulton, for a total capacity of 30 M.G.D. The major difference in the two systems if they were both in the same physical condition, which they are not, would be better water quality from Silver Lake and the ability to store water at Basin Reservoir during spring run-off. At present, we must deplete Basin Reservoir when the Big Hole River turbidity level is not acceptable. The reduction in storage creates water restrictions as well as increased pumping costs. The Big Hole River water, which is our poorest quality and most expensive to pump, would be our make-up water during peak demands.

We would maintain these sources and transmission systems and use the cash generated by the increased base to upgrade the distribution system,

EXHIBIT #11 (Continued)

reservoirs and equipment. When filtering is enforced, we could have the options of mixing and matching the three main water sources to the state-of-the-art equipment available at that time. We could also have the ability to trade the water needs with the mine for unfiltered water. We would have the ability to filter two sources rather than four. Prior to filtering, the distribution system would have to be adapted to receiving water from the west, compared to the south, north, and west, as it is now.

Meters would be installed into the system as desired to fit in with cash flow and rate shock.

The proposed system allows for immediate improvement of water quality, volume, water management; and hopefully, improved pressure. If our present plans do not correct the pressure problems, the proposed system allows more options. It also allows Butte Water Company to help spread the rate shock to the consumer.

The capital expenditure for the proposed system and the cost and ability to finance it, would compare with the costs to upgrade our existing system; and financing would be most difficult. The consumers costs of service would increase in either case, but the consumer would not notice a difference in water quality or water restrictions if the existing system were renovated.

The master plan addresses most needs in a time-frame which moderates rate shock. Most important, the master plan is operational, as well as financially possible.

Water for Thirsty Cities

George A. Whetstone

A graduate of an accredited curriculum in City Planning, particularly if the ink were still wet on his diploma, would never have selected the sites on which Virginia City, Butte, or Johannesburg stand.

According to the textbook, a city should be located on a river, or, perhaps, a navigable lake—preferably with lock-free access to the sea. Why, even Timbuktu, the classic example of inaccessible remoteness, is on the Niger.

Such locations may, of course, involve problems with floods and with periods of low discharges during which navigation may be hampered and saline water may invade the aquifers and the intakes of the water treatment plants. Raw water quality may, in fact, be dubious at all stages of the river. This, however, is an inconvenience with technically easy, even if sometimes expensive, solutions. The city acquires an upland watershed and brings a piped supply, usually by gravity and possibly even with some hydroelectric generation, to distributing reservoirs in town. Alternatively, if a productive aquifer is available, a groundwater supply may be developed and protected from encroachment.

Such solutions have even served the very few cities, such as Amarillo and Lubbock, which somehow took root by dusty arroyos and outgrew the expectations that any rational pioneer could ever have entertained for them.

Even in rugged mining regions, the prevalent pattern of development has been to erect a boarding house at the shaft or adit head, to place an ore reduction mill at a lower elevation, and to establish a townsite on a perennial creek with rail or highway connections to a regional supply point, usually situated in a broad valley in the foothills. Such a chain in Colorado would be represented by Silverton and Durango or Silver Cliff and Pueblo. Problems could, of course, have arisen had the satellites such as Silverton, Telluride, Ouray, or Central City really boomed. Leadville and Cripple Creek, the two Colorado Camps which did, fortunately had ample room for the expansion which occurred and ample available water. Such was not the case on the Comstock.

VIRGINIA CITY*

The first bonanza camp to become a metropolis was Virginia City, Nevada. Here the few early prospectors had secured their water from small streams and springs. These supplies had been augmented by the water tapped in driving mining tunnels into the Virginia Mountains. Some tunnels were, in fact, driven primarily to develop water. And, in many, water was the most valuable mineral found.

---

*Sizes, dates, lengths, quantities, etc. cited are taken from what would appear to be the most reliable reference. In many cases quite different values may also be found.

The Virginia Range has an average elevation less than Virginia City's 6200 feet; it is in the rain shadow of the Sierras, and the groundwater encountered at depth is too highly mineralized to be usable for municipal or industrial supply. Water could have been pumped from the Carson River, six to eight miles away and 1700 feet lower, but the cost would have been prohibitive.

Thirty miles to the west the well-watered Sierras rise a thousand feet or more above the city, but to reach them it is necessary to cross the Eagle and Washoe Valleys, 1200 to 1500 feet below Virginia City and nearly 1800 feet below the divide over which an aqueduct must pass.

The decision, in 1871, of the Virginia and Gold Hill Water Co. to go to the Sierras for water involved designing pipe for more than twice the pressure ever before used anywhere. Hobart Creek, on the east slope of the Sierras, was dammed and a wooden flume 18 inches deep, twenty inches wide, and 4.62 miles long was erected to carry 2.2 million gallons per day to the inlet of the inverted siphon. This latter consisted of seven miles of riveted pipe with an internal diameter of 11.5 inches and with thickness varying from 0.062 inches near the ends to 0.312 inches at its lowest point. From the outlet on the summit of the Virginia Range an additional 9.70 miles of flume led the water to distributing reservoirs above Virginia City and Gold Hill.

Feverish activity in the Comstock mines in the early '70's led to a paralleling of the entire system of pipes and flumes in 1875. Even the augmented supply, however, proved to be inadequate when a fire destroyed much of the town in October 1875; Hobart Creek and its reservoir become badly depleted by late summer.

For an additional supply the company secured rights to Marlette Lake, an artificial reservoir at 8000 ft. elevation within the Lake Tahoe drainage. They raised the dam and built 4.38 miles of flume running northward to a 4000-ft. long tunnel. Another flume, 8.25 miles long, was extended northward from the tunnel inlet to intercept the waters of creeks flowing to Lake Tahoe. From the tunnel outlet 2.77 miles of flume led to the reservoir on Hobart Creek. A third pipeline laid in 1877 parallel to the two earlier lines raised the system capacity to ten million gallons per day. The total investment was about $2,200,000.

The Comstock declined, but the system served well until the mid-1950's when old age began to take increasing toll. The State of Nevada acquired the system in 1963. Many portions are still in operation, and a general rehabilitation with a significant portion of the supply being destined for Carson City, in Eagle Valley, is under study at present.

BUTTE

Butte, Montana, is nearly encircled by the Continental Divide. Silver Bow Creek, which drains this summit valley, escapes through a canyon in the western rim to join the Clark Fork of the Columbia River.

The first prospectors, in 1864, found adequate water in the creek and its tributaries; shallow wells provided for the residents of the camp through the 1870's. As mines went deeper, however, they drained the aquifer supplying the wells—and the water produced by the mines was a dilute sulphuric acid unfit for any domestic, industrial, or agricultural use.

The Silver Bow Water Co., organized in 1881, brought the first supply from Bull Run Gulch, north of town, in a seven-mile wooden flume. To this they added an undependable supply from Yankee Doodle Creek, and, for a brief period, pumped the polluted waters of Silver Bow Creek from a point a mile and a quarter below the city. They secured water rights in a gulch west of town, and brought a supply from Basin Creek, a tributary of Silver Bow Creek south of town, through eleven miles of pipes and flumes. Meanwhile, the city tripled in population within the decade of the 1880's and the water demands of the mines, mills, and smelters increased at an even greater rate.

Engineering News had observed in a note in its issue of 10 December 1887 that "The new water supply of the Silver Bow Water Co. has been condemned as unwholesome: being contaminated by sewage and the seepage from the graveyard."

The Anaconda Company, owner of nearly all the mines and mills of Butte, established their smelter at Anaconda, 45 miles to the west, and built the Butte, Anaconda and Pacific Railroad to transport ore to the water needed to process it. They also let a contract for a tunnel 4000 feet long under the Continental Divide to divert water for their mines from Boulder Creek. They offered to sell some of this water to the city, but the negotiations for a franchise bogged down in City Hall politics.

In February 1890 the city granted a franchise to the Silver Bow Hydraulic Mining Company, which held water rights on Divide and Jerry Creeks on the eastern slope, for a supply from there. The resulting fracas between the three water companies and their supporters, including three newspapers never noted for their moderation, was long and bitter. To shorten a very involved tale, let it merely be mentioned that the Butte City Water Company was organized, that it purchased the Silver Bow Water Company and the Silver Bow Hydraulic Mining Company, and that it secured a franchise in May 1891 to bring a supply of water to Butte from Divide and Jerry Creeks by means of a pipeline which would cross the main range of the Rocky Mountains in Deer Lodge Pass at an elevation of 5700 feet.

During 1892, *Engineering News* carried a report on the construction, by the company, of a dam on Basin Creek, a tributary of Silver Bow Creek, and the laying of a pipeline to a distributing reservoir at Butte. The advertising pages of the same volume carried announcements that the City of Butte, having found alleged violations of its franchise requirements, was seeking new applicants for a water supply franchise.

The Butte City Water Co. was reorganized as the Butte Water Co. in 1898. In 1899 it installed a pumping plant on the Big Hole River capable of lifting 15 million gallons per day over the Continental Divide to its reservoirs on Basin Creek.

The same company still serves Butte. Keeping pace with a population which trebled again in the 1890's, the company established three independent sources of water. Yankee Doodle Creek, developed by means of two dams, lies entirely within the drainage basin of Silver Bow Creek. The Basin Creek development, augmented by a gravity diversion through a pass from Fish Creek, obtains 4 million gallons per day from the western slope and 1.5 million from the eastern slope. The Big Hole River supply, all from across the divide, utilizes an 840-foot pump lift from the Big Hole to a reservoir on Divide Creek, plus water which drains by gravity to the reservoir. Transmission lines of steel and wood stave pipe had been paralleled by 1920. A new 36-inch line from the Big Hole was completed recently.

The fifteen square mile area served by the company, including Butte and surrounding suburbs, ranges in elevation from 5410 to 6368 feet. To maintain appropriate pressures in the distribution system seven zones, based on elevations served, have been established. Reservoirs have been constructed and piping interconnections installed between the three independent sources in such a way that pumping is minimized and that continuity of service and ability to react to emergencies is maximized. That emergencies could arise is easily understood when one reflects that there are many more miles of mine tunnels under Butte than there are of streets on the surface, and that the average depth of frost penetration in one of Butte's nine-month long winters is about five feet. Under such circumstances landslips are not uncommon.

Butte is the largest city in America which began as a mining camp and owed its prosperity almost exclusively to the mining and metallurgical industries. It is by far the largest American city in such close proximity to the Continental Divide. In Africa, however, the world's largest mining camp sits astride the somewhat less precipitous divide between the Atlantic and the Indian Oceans.

THE WITWATERSRAND

Gold was discovered on the Rand, 35 miles from the Vaal, the nearest river, and more than a thousand feet above it, in 1886. Springs and wells provided an expensive and erratic water supply to the early prospectors. During the drought of 1895 water conveyed by mule cart to the dusty mining camp of Johannesburg sold for 6 pence per bucket on the street corners.

Rational, financially competent water management was inaugurated in 1903 with the establishment of the Rand Water Board, a public agency which purchased the various private holdings, rehabilitated the wells, and developed a ground water supply of 25 million gallons per day fed by a catchment with an area of 308 square miles in the Klip River Valley. An unprecedented 900-foot pump head was involved.

By 1914 this augmentation had been outgrown, and the decision was reached to dam the Vaal River to capture the unappropriated surplus flow. A 460-foot pump lift was employed to raise Vaal River water to the earlier intake.

Unlike Virginia City which reached its zenith in the 1880's and Butte which peaked shortly after World War I, Johannesburg has continued to grow—and the service area of the Rand Water Board, which includes Pretoria, Johannesburg, several smaller localities, the gold mines, and the major industrial complex of Africa's most dynamic nation, has continued to expand. The problem posed in providing a water supply has assumed national and international significance.

The Vaal is a tributary of the Orange; neither is a great river by any absolute standards. In fact, the Orange below the confluence has been dry on a number of occasions. With the exception of a small fringe area along the western summit of the Drakensberg Mountains, the entire Orange-Vaal watershed is semiarid to arid. The outfall to the Atlantic occurs in the Namib Desert. Water rights to the dependable flow of both rivers were acquired early by irrigators, and stored water is subject to substantial evaporation losses. Thus, after a scond dam was completed on the Vaal, the river's full potential from in-basin sources alone was reached.

The alternatives faced in the early 1960's were to limit the growth of the nation's heartland by requiring a dispersal of industry to the east coast or to divert water into the Vaal River basin. All feasible and some apparently visionary water importation schemes were studied.

Augmentation from the Orange or its upper tributaries would be relatively simple. Such was provided for in a comprehensive plan adopted for the complete regulation of the Orange River in South Africa by means of a series of dams and diversions. Rather than pumping water to the Rand Water Board's intake, however, the same effect was accomplished by supplying the downstream irrigated areas with water from the Orange River and diverting their Vaal River supplies to the Rand.

A geographically obvious—but politically difficult—possibility of bringing water of excellent quality to the upper Vaal exists in the Lesotho Highlands project. This would involve the creation of a major reservoir on the headwaters of the Orange River in the nation of Lesotho. From here, water which would reach South Africa by natural channels, picking up a heavy silt load in the process, could be diverted by pipeline to the Rand, generating hydroelectric power on its way. The development in Lesotho of its water supplies and of the transportation network required for the construction and maintenance of the project would provide a significant economic stimulus to this developing nation.

One of the world's outstanding accomplishments in hydraulic engineering, the Tugela-Vaal project, provides for the diversion to the Vaal of waters from the Tugela River which flows across Natal to the Indian Ocean. Here aqueducts intercept high tributaries and lead the water to a reservoir which is itself in the headwaters of the river. A pump lift to a transdivide tunnel permits storage in Sterkfontein Reservoir from which releases can be made to either the Vaal or the Tugela as need dictates. Hydroelectric power development has been skillfully integrated to permit a further saving of water which would otherwise be used in thermal powerplant cooling. It has been calculated that an acre-foot of water in Sterkfontein Reservoir provides three additional useful acre-feet on the Vaal in that it reduces evaporation losses and losses due to spillage, during floods, of water being held in storage to assure a dependable supply. Further developments on the Tugela have been planned; they will be implemented as needs develop.

For the more distant future diversions from the "northern rivers"—the Okavango, the Zambesi and its tributaries, and the Cunene—are possible. These would involve negotiations with South Africa's neighbors, Botswana in particular. In the recent past the chances for success in such a venture appeared to be remote despite the examples set of mutually beneficial cooperation in hydroelectric generation on those same rivers at Cabora Bassa, Kariba, and Rua Cana.

Now that Russia, Cuba, and China have shown themselves to be actual threats to the existence of many African nations, the ideological differences between potential allies seem to be of much less significance than was the case before the "liberation" of Angola. The development potentiality foreseen by D. C. Midgley, Professor of Hydraulic Engineering at the University of the Witwatersrand, ten years ago may well occur. He stated

> "Unfortunately, gifts of food during times of famine have, in many instances, destroyed the will of the people to improve their produc-

> tion potential. It is easy, for those who have, to sooth their consciences by giving to those who have not, but the resulting disturbances are hardly worth a passing balm to the conscience. Persons do not like to be beholden to others—neither do nations—and when denied the opportunity to escape gratuitous dependence usually react with growing hatred.
>
> "It is true that if half the world starves the other half does not sleep, but peace and popularity cannot be bought by pouring in misdirected aid . . .
>
> "It is in the field of water and power development that South Africa's needs can be the medium through which her neighbours can become prosperous. It is not a question of advocating that the Republic [of South Africa] should become vitally dependent on her neighbours, but rather that an interdependence be created to the mutual advantage of all the Southern African countries, culminating, perhaps, in a form of common market or a co-prosperity bloc."

Thus it may come about that the thirst of a dusty mining camp, metamorphosed into one of the world's great cities, may have provided the incentive for a solution easing the tensions and improving the economic well-being of all Southern Africa.

RECEIVED
APR 10 1987
MONT. P. S. COMMISSION

MEMORANDUM OF AGREEMENT

THIS MEMORANDUM OF AGREEMENT executed this _____ day of April, 1987, by and between DENNIS R. WASHINGTON (Washington), and the BUTTE WATER COMPANY, a New Jersey corporation (Company);

WITNESSETH:

WHEREAS, Washington is the owner of a surface water collection, impoundment, pumping, flowage and transmission facility, with water rights appurtenant thereto, known as the Silver Lake Water System (SLWS) located in Deer Lodge and Silver Bow Counties, Montana; and

WHEREAS, Company is a water utility providing water service to the communities of Anaconda and Butte, Montana; and

WHEREAS, Company requires the use of a portion of the capacity of the SLWS to supply its water customers in the Butte, Montana, customer service area and will require financing for the purchase of capital improvements and additions to its Butte, Montana water utility system; and

WHEREAS, Washington and the Company have come to a preliminary agreement on the basic terms and conditions of a lease of a portion of the capacity of the SLWS and for the financing of the purchase of capital improvements and additions to Company's Montana water utility system;

NOW THEREFORE, the following basic terms and conditions of a proposed lease agreement and agreement to finance the purchase of capital improvements and additions to the Company's Butte, Montana water utility system have been agreed to:

I. PROPERTY SUBJECT TO LEASE:

An undivided 11/18 of Washington's right, title and interest in and to the Silver Lake Water System (SLWS), including and together with all water rights, water courses and real property appurtenant thereto, lakes, reservoirs, dams, flumes, pipes, pumps, headgates, ditches, transmission lines and other appurtenant real and personal property located in Deer Lodge and Silver Bow Counties, Montana (Leasehold Interest).

II. TERM OF LEASE:

Initial term of ten years beginning upon the date of the commencement of the operation of the SLWS as an integrated component of the Company's water utility system.

Option to renew for an additional term of ten years upon the same terms and conditions.

III. OPTION TO PURCHASE:

Company will be offered an option to purchase the Leasehold Interest during the primary term of the lease for the current appraised value of $6,905,000.00.

Company will be offered an option to purchase the Leasehold Interest during any renewed or extended term of the lease for the then current appraised value of the property to be determined on the date of the renewal of the lease.

IV. CONDITION PRECEDENT TO LEASE:

Prior approval of the terms and conditions of the lease by the Public Service Commission of Montana pursuant to appropriate Commission proceedings and action.

V. LEASE RENTAL:

The annual lease rental will be $854,839.00 payable semi-annually with the first semi-annual payment due and payable six months from the date of the commencement of the operation of the SLWS as an integrated component of the Company's utility system.

VI. LEASEHOLD EXPENSES ASSUMED BY COMPANY:

Under the lease agreement, the Company will assume the responsibility and liability for the payment of the following expenses associated with the Leasehold Interest:

(1) 11/18 of the operating and maintenance expenses associated with the SLWS, including insurance.

(2) 11/18 of the real and personal property taxes levied against the SLWS.

VII. OPERATION OF LEASEHOLD INTEREST:

The Leasehold Interest will be managed and operated in such a manner as to provide Company with a minimum flow of eleven million gallons of water per day (11 M.G.D.) at a take-off point from Washington's 36" water transmission line in the vicinity of the Company's Summit Valley pump station.

Washington and Company will coordinate the operation of the Leasehold Interest so as to provide the most efficient use of the SLWS by Washington and Company for their separate interests.

VIII. TERMINATION OF LEASE:

A. By Washington:

(1) Upon any breach by Company of the terms of the lease, upon written notice of breach, and after

providing Company six months in which to cure or correct such breach.

(2) Upon any action taken by the Public Service Commission of Montana which, in the opinion of Washington, materially affects the obligations of the Company for the payment of the lease rental and/or payment of the leasehold expenses assumed by the Company.

(3) Upon any action or decision of any court of the State of Montana or the United States which would reduce, by any amount or volume, Washington's legal or equitable right to the impoundment, flowage, transmission, diversion or use of the waters of Warm Springs Creek and the tributaries thereto necessary to the transmission of a minimum of eighteen million gallons of water per day (18 M.G.D.) from the diversion point at Myers Dam to Washington's mining operations in the vicinity of Butte, Montana.

B. By Company:

(1) Upon any breach by Washington of the terms of the lease, upon written notice of breach, and after providing Washington six months in which to cure or correct such breach.

(2) Upon any action taken by the Public service Commission of Montana which, in the opinion of the Company, materially affects the ability of the Company to meet its obligations for the payment of the lease

rental and/or payment of the leasehold expenses assumed by the Company.

(3) Upon any breach of the capital improvements financing agreement between Washington and Company relating to the financing of the planned capital improvements scheduled by the Company for the lease years 1987-1992 as described and identified in Schedule A to this Memorandum of Agreement.

IX. AGREEMENT TO PROVIDE DEBT CAPITAL:

Washington agrees to provide the Company with debt capital for the addition or replacement of utility plant facilities under the planned capital improvements, loan schedule and interest rates under the terms and conditions set forth in Schedule A to this Memorandum. Each loan covered by this Agreement shall be separately documented by a good and sufficient promissory note secured by appropriate mortgages and collateral security agreements.

This agreement to provide debt capital terminates upon termination of the lease by either party or upon default by the Company in the payment of any principal or interest payment due and payable under any promissory note given under this agreement. In either such event, the principal and interest on every outstanding promissory note shall become immediately due and payable.

Dennis R. Washington

BUTTE WATER COMPANY

By

This material is the result of tax-supported
research and as such is not copyrightable.